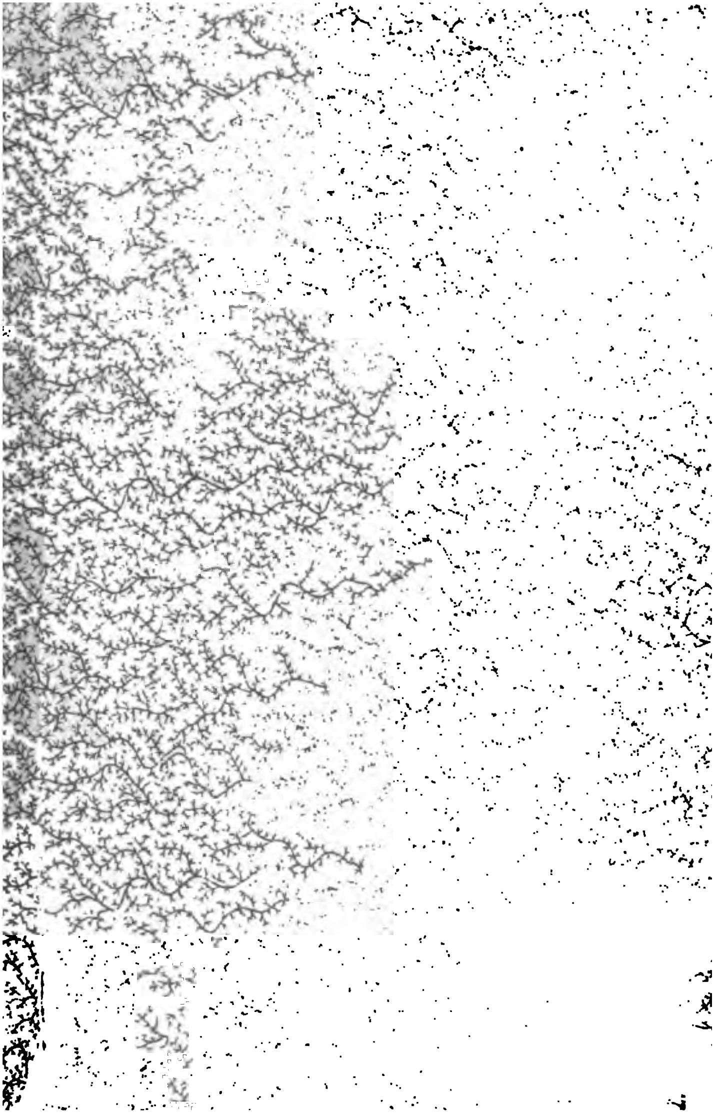

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BRITISH
MANUFACTURING INDUSTRIES.

BRITISH

MANUFACTURING INDUSTRIES.

EDITED BY

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METALLIC MINING AND COLLIERIES,
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COAL,
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BUILDING STONES,
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PREFACE.

THE object of this series is to bring into one focus the leading features and present position of the most important industries of the kingdom, so as to enable the general reader to comprehend the enormous development that has taken place within the last twenty or thirty years. It is evident that the great increase in education throughout the country has tended largely to foster a simultaneous interest in technical knowledge, as evinced by the spread of Art and Science Schools, Trade Museums, International Exhibitions, &c.; and this fact is borne out by a perusal of the daily papers, in which the prominence given to every improvement in trade or machinery attests the desire of the reading public to know more about these matters. Here, however, the difficulty commences, for the only means of acquiring this information are from handbooks to the various manufactures (which are usually too minute in detail for general instruction), from trade journals and the reports of scientific societies; and to obtain and systematize these scattered details is a labour and a tax upon time and patience

which comparatively few persons care to surmount. In these volumes all these facts are gathered together and presented in as readable a form as is compatible with accuracy and a freedom from superficiality; and though they do not lay claim to being a technical guide to each industry, the names of the contributors are a sufficient guarantee that they are a reliable and standard work of reference. Great stress is laid on the progressive developments of the manufactures, and the various applications to them of the collateral arts and sciences; the history of each is truly given, while present processes and recent inventions are succinctly described.

BRITISH MANUFACTURING INDUSTRIES.

METALLIC MINING.

By Warington W. Smyth, M.A., F.R.S.

The present period is one of great change, anxiety, and uncertainty in many branches of metallic mining in this country. In addition to the pre-eminence which the productiveness of our western counties, Cornwall and Devon, has from time immemorial enabled us to hold in the supply of tin, Great Britain has for upwards of a century occupied a most remarkable position as the chief producer in the world of the metals copper, lead, and iron. And besides these, fluctuating, although sometimes large and remunerative, quantities of the ores of zinc, manganese, and sulphur (iron pyrites) have been raised, in full and successful competition with foreign supplies.

But within the last two decades the increased activity of Continental and of remote colonial enterprise has brought rivals into the field, who, in some instances, have succeeded in coping victoriously with our poorer and deeper mines. The check thus administered from

time to time to our production has caused a large emigration among the miners, who thus again, scattered through various distant parts of the world, aid in producing abroad the serious amounts of mineral which depress prices, and render the position of the home mines more precarious.

Most notably is this shown with regard to copper. Although important mining for the ores of this metal in England only takes its rise from the latter part of the seventeenth century, we have for above one hundred and fifty years enjoyed a striking pre-eminence in its supply, and in the year 1856 had attained to an annual production valued at 1,363,003*l.* But the tables have been turned, and what with the lessened demand for shipbuilding and sheathing, and other purposes, the large quantities of rich ores produced in shallow mines in South America, at the Cape, and in Australia, and at the same time the singular absence of any good discoveries in our own country, we have suffered a decadence which has brought down our annual supply, in 1873, to the computed value of 342,708*l.* The state of our tin mines has, during the same period, been a subject at times of grave anxiety. Their depth, and the expenses of the dressing processes, have made it a hard fight to stand up against the concurrence of the surface-raised stream tin from Banca and other East Indian localities; and no sooner do they emerge successfully from the conflict than they are threatened again, within the last three or four years, with a similar influx from New South Wales and Queensland. But the home production has steadily increased, and there

seemed to be no doubt that the British tin mines would hold their own, when a fresh source of danger arose in the enhanced price of coal, certain to ruin many, and greatly impairing the prospects of all analogous undertakings in which fuel is an essential of life.

Turning to the lead mines, we find that the individual adventures have not what may be called *good lives*, and that the names of the specially productive mines seldom stand in the same high place for many years together. But on the whole the British districts noted for this metal, distant and different as they are from one another, keep us well in the van of the world, notwithstanding the vast quantities which from time to time have been thrown on the market by the Western States of America, by Spain, and by the island of Sardinia.

In taking thus a first *coup d'œil* at my subject-matter, I may omit to notice the metals of smaller importance, but must pause a moment before that marvel, the British iron trade, in which it is notorious that an unexampled position has been won by the enormous supplies of various kinds of iron ores from our own mines, together with an abundance of cheap mineral fuel.

The newer phase shows many of our old sources of iron ore to be exhausted, and a vast importation to have commenced from Spain, Africa, Elba, and even North America, to fill the void caused by the demands of a time of unusual activity. And the question arises, how far a system of importation of the ore to be smelted by our native fuel will in future be compatible

with the high prices lately attained by coal. Our insular position, no doubt, in this as in so many other points of view, tells much in our favour; but unless our own mines can supply the chief bulk of the ore needed, and coal and coke be obtained at rates contrasting more favourably with those of the Continent, it may be feared that the axe is already laid at the root of the tree.

I shall therefore, without entering into the earlier history of British mining, take a brief survey of the mines of the different metals as they are grouped in our several districts, and examine into the circumstances under which they may or may not still be expected to be productive. And this summary I shall follow up by a glance at the various operations of working the mines, referring more particularly to some of those modifications which have been, or are to be, made to suit the general advancement of the art, or particular exigencies of the times.

Gold Mines.

Although at the present moment only a single gold mine is working in our Islands, several have within the last few years been more or less tested, and the circumstances which surround them, as well as the causes which in part have prevented their more thoroug development, are so curious as to deserve a longe notice than my space admits of. It is in the lowe Silurian slaty rocks, between Bala and Barmouth North Wales, that gold-bearing lodes have been distinctly made out, and more particularly bet

Dolgelly and Barmouth, where in two or three instances a tolerable amount of mining work has been done, whilst in a great many more a few "specimens" only have been found; money has been vigorously transferred from one person's pocket to another's, and the mine workings have been either *nil* or of a very illusory character.

The veins range in a direction averaging about E.N.E. and W.S.W., and usually contain—besides the quartzose matrix, which, with fragments of the adjoining rock, or *country*, makes up the chief mass of the vein—calcspar, varying from a coarsely crystalline to a fine marbly structure, with portions of galena, zinc-blende, copper and iron pyrites, tetradymite, and sometimes pyrrhotine. The gold is generally imbedded in the sparry constituents; more rarely—as in Cwmheisian—in the blende; sometimes in very delicate specks, films, and crystalline wire-points; at others in bold groupings, which at Castell Carn Dochan, Prince of Wales, and Dolfrwynog have formed specimens that will vie with those of California and Australia. In the mine called Vigra and Clogau, some small workings were commenced in 1854–5, more particularly on a vein called "St. David's lode," running closely along the lower or northern border of the Silurian rocks, and therefore almost abutting upon the Cambrian. It was at a time when a gold-mining mania raged for many months, and when it was somewhat difficult to be satisfied as to the origin of some of the numerous rich specimens, said to have been broken from different localities within this and the adjoining districts. Then

an almost entire stoppage of operations took place, till a similar outburst occurred in 1861–65. Scores of so-called "mines" were set agoing, mostly on paper; real operations of sinking and driving were carried out in but a few instances, of which the above-named, with the "Welsh gold mine," and, more recently, Gwynfynydd, are the most observable. The levels (or galleries) in Clogau mountain were pushed farther, and opened out a vein from two to five or six feet in breadth, which, in its auriferous portions, was a privilege to see, and which yielded, in all, 40,000*l.* worth of gold, a large proportion of it in so short a time, and with so few men, that the profit was really very great. And although, from not meeting with other rich portions of the vein, and perhaps from unwise outlay of money on matters of machinery, this mine for a while ceased to work, and the others have similarly come to a standstill, I cannot but express the opinion, after visiting the scene of action over and over again, that these Merionethshire gold lodes have been abundantly extolled, trafficked in, misrepresented, and abused, but have not yet been thoroughly or fairly proved.*

I need scarcely discuss the conditions under which gold has been discovered, and worked too, by hundreds of persons in the alluvial material on the banks of streams in Wicklow, Ireland, and more recently in Sutherlandshire. Suffice it to say that in these instances, as well as in the older known one of Lead Hills, in Scotland, there has been difficulty in determining the origin of the stream gold, and that

* The revived workings at Clogau are now very encouraging *(1875).*

although the deposits may just pay the labour of a few peasants, it seems very doubtful how far any proportionately increased yield may be expected to follow the outlay of capital.

Silver Mines.

The British mines yield annually about 200,000*l.* worth of silver; but very little of this is contributed by the true minerals of that precious metal; it is almost all obtained from the argentiferous galena, or "blue ore" of the lead mines. Of true silver workings we have had within this century several very curious examples,* as Herland, North Dolcoath, Wheal Ludcott, Wheal Duchy or Brothers, and a few more in Cornwall; but they have endured only for a short time, the lodes being more than usually capricious and limited in the extent of their metal-bearing portions. A similar fate befell a spirited attempt to open a silver vein in Sark, in the Channel Islands; the ores, as in the Cornish instances quoted, were mostly chloride of silver (kerargyrite) in the ferruginous (gossan) shallower workings, with silver glance (argentite) and ruby silver (pyrargyrite) in the deeper parts. I am unaware of any *à priori* reason why rich and lasting silver veins should not be found in some of our older schistose rocks, as in the Harz, Bohemia, or Norway; but, so far, experience has proved them to occur in a singularly abrupt and fragmentary form, mostly in cross veins, or limited to junctions of such with others.

* *Vide* W. J. Henwood on the "Metalliferous Deposits," &c., Trans. R. Geol. Soc. of Cornwall, v. 41, 65, 140, and viii. *110, 710; Salmon*, 'Mining and Smelting Mag.,' ii. 78.

At the present moment the silver ores raised are only argentiferous varieties of tetrahedrite or *fahl-erz*, which, in subordinate spots and strings, is associated with the lead ores of the old Treburgett mine in Cornwall, and the Foxdale in the Isle of Man, and are not sampled or sold separately from the lead ores.

Lead Mines.

For the last twenty years our British mines have been raising, annually, from 73,000 to above 100,000 tons of dressed lead ore, yielding from 54,000 to 73,400 tons of metallic lead, and from 496,000 to 840,000 ounces of silver extracted by the smelters. This immense production, averaging above a million and a quarter pounds sterling in annual value, is obtained from some hundreds of mines scattered through the median and western ranges of hills, from the lowlands of Scotland down to the south coast of Cornwall and Devon. We may conveniently, in a geological point of view, as well as for the more clearly selecting some of the main peculiarities, group them as follows:

A. Lead mines of the limestone formations generally poor in silver.

B. Lead mines of the slaty rocks, often rich in silver.

C. Lead mines in granite, variable as to silver, some very rich.

A. *The Northern District.*—Nowhere does a mor well-marked, interesting, and productive area e: than that tract of mountain or carboniferous limest

which constitutes the great bulk of the heather-clothed moorlands extending from the Roman wall down into Yorkshire. The formation is not, as in Derbyshire or South Wales, made up mainly of simple limestone, but consists of alternations of limestone, grit (*hazle*), shale (*plate*), *grey beds* or indurated clays, and a celebrated bed or *sill* of whin-stone. These strata, the position and thickness of each of which is a matter of close study with the miners, lie undulating over vale and fell for about twenty miles in width and eighty in length, often showing long lines of outcrop, with gentle foldings and irregularities, but never violently contorted, as the deeper-lying schists are apt to be. Through these strata, the long lines of ancient fissure now found occupied by spars and ores of lead and zinc take their course; in some parts, as at Alston Moor, Nent Head, Rookhope, and Weardale, very many of them in near proximity, in other parts of the region less obvious and wider apart.* The "right running" veins have a bearing of nearly east and west, but are yet subject to deviations which cause junctions at various angles, and doubtless in somewise affect their productiveness. Varying in this respect at even a few miles distance, some of these lodes "make well" in particular beds only, all of them generally agreeing to do badly in the shale or *plate* ground.

About Alston and in North Yorkshire it has been chiefly the "Great Limestone," 60 feet thick, that has been the successful "country" for the veins: in Tees-

* See Forster, 'Section of the Strata,' 1821; and Wallace on 'Lead Veins,' Stanford, 1861.

dale the "firestone" beds; whilst in Weardale and at Stonecroft, in Northumberland, the "whin-sill," elsewhere regarded with fear and trembling, has produced courses of ore of exceeding value, and at a depth in the measures which promises well for future exploration.

But although these east and west lodes have been the most regular in their yield, the cross veins, which in some districts produce a different, and in others no useful mineral whatever, have in the Alston Moor district been in several cases highly productive. At Nent Head and Brownley Hill they have thus been bunchy, discontinuous, and strangely irregular in their habits, but have nevertheless yielded large returns. And in most of the mines in this neighbourhood where they have been worked in the upper sills, accessible by adits or levels from the hill sides, the expenses have been so small as to leave a most unusual proportion of profit. Let us see what one or two of the more noted lodes have done. Rampgill vein, which passes through the hill between the Nent river and the Tyne, near Garrigill, produced, from 1704 to 1853, a total of 315,770 *bings* (at 8 cwt.), or 126,258 tons, the amount in some years being 3000 or 3500 tons. In the early part of the century, the pearl of these uplands was discovered in the little mine of Hudgill Burn, where, without machinery and employing never more than one hundred men, no less than 14,000 *bings*, or 5600 tons, of merchantable ore were raised in a single year. But, strange to say, this hill side, once full of little ventures, is now almost deserted. The high rate of

wages in the coal and iron fields has tempted the men away; the more accessible parts of the veins have been exhausted; and the deep Nent Force adit, projected by Smeaton in 1775 as a boat level, for the unwatering and exploration of the veins in the deeper strata, has, up to the present time, not been attended with success.

An enormous measure of productiveness still marks the mines of Mr. Beaumont in Allendale and Weardale, and those of the London Lead Company at Nent Head and in Teesdale; whilst numerous others, worked by private companies, and very notably the Stonecroft Mine in Northumberland, and the Arkendale and Old Gang mines in North Yorkshire, contribute largely towards the grand total of 27,562 tons raised by the northern counties alone.

No miner, however, with eyes to see, can fail to regard these lodes under another aspect also, viz. their beauty of composition and the variety of minerals that diversify the occurrence of the ores in particular groups, characters hardly to be seen again till we encounter them in the remote south-western counties. The splendid crystallizations of many-coloured fluor-spars in Weardale, Allenheads, and Teesdale, the lustrous jet-black zinc-blende of Nent Head, the many-shaped, elegant crystals of calcite, and the somewhat rarer baryta minerals, witherite, alstonite, and baryto-calcite, most noted at Fallowfield and at Brownley Hill, these are all among the chief ornaments of mineral cabinets throughout the world. Nowhere, however, can they be seen to so much advantage as in

a rich "heading" underground, or in one of the *flats* that run off like tongues from some of the lodes into the Great Limestone, where with the glittering cleavage planes of galena, and the sparkling, if useless, facets of quartz and pearl-spar, the miners ply their task in the midst of a sort of Aladdin's cave, with which few scenes of palatial adornment can vie.

The wide area through which these veins extend, and the probability that some of them, at least, will make downwards into productive sills not yet explored, leave a prospect open that much wealth may yet remain to be discovered.

Derbyshire.—The lead mines of this county, which have been worked from a very remote antiquity, exhibit the results of exhaustion in the fact that all the chief well-known lodes have been worked down to a level, at which overpowering quantities of water occur. With a few exceptions, the mining of the present day, although it brings out the fair result of 4442 tons of ore (in 1873), is limited to "poor men's mines," or small adventures, in which with none but the simplest mechanical aid old works are explored again, or trials made in small holdings of ground which would scarcely invite the attention of a company. The permeability of the jointed limestone to water is the cause of this peculiarity—one checked to some extent where the beds of volcanic-ejected matter, "todt-stone," with their very variable thickness, alternate with the limestone strata. The interruption by this material to the bearing parts of the lode, at one time considered to be complete, has now been shown to be only partial; indeed, the chief mine of the last few years, the Mill

Close mine in Darley Dale, fairly discovered by the bold speculation of its owner, Mr. Wass, and said to yield above half of the above return, is worked between shale on one side and the todt-stone on the other. The general course and the medium size and composition of the veins remind one much of those of the North, only that here quartz is exceedingly unfrequent, and a yellowish earthy barytes, "cawk," very abundant. No doubt a few good points may yet be struck upon, but the limited area of the Derbyshire limestone offers no great prospects for the future.

Flintshire and Denbighshire.—The general run of a long series of parallel veins which course across the mountain limestone into the millstone grit, and are afterwards, or farther east, observable as "faults" in the coal measures, is intersected by a set of strongly-marked cross courses, traceable for many miles in length, generally barren, but here and there, as above Holywell, offering an exceptional richness in lead ore. The amounts raised from some of these mines in former days are fabulous; but they have produced in parts of the veins galena in a condition of purity and solidity hardly equalled elsewhere. When poor, the same veins are apt to be filled with a dead, dull opaque calc-spar, or with mere clay; and a great feature in most parts of both counties consists in the heavy feeders of water encountered. It is no uncommon thing to see two or three large pumping engines at a single or closely contiguous mines, whilst the pumps are commonly of from 18-inch to 22-inch calibre. Hence the expenses of keeping open the deeper mines in these counties have been a serious drawback, and of late years it has been

mainly by two or three concerns that the returns have reached the high amount of 9000 tons of lead ore. Among these, however, and placed at the two extremes of the district, is Minera, one of the most productive mines in the world, figuring for above 5000 tons, and Talargoch, near Rhyl, a very interesting deep working, for above 2000 tons.* A remarkable feature consists in the fine deposits of cerusite, or white-lead ore, which have occurred in several of the mines near Mold, where the veins intersect the sandstones of the millstone grit; and another in the pipe veins, quite as noticeable in parts of Derbyshire, where the lead ore has "made" upwards and downwards at a steep angle in channels of but short horizontal extent. These, which have sometimes yielded a great amount of very pure ore in a small compass, are sometimes seen in Flintshire either empty, or filled with valueless material, and exhibit as I cannot but think the clearest indications of having been eroded by a flow of water, and then filled in a manner analogous to the lodes.

It is obvious that where so many and such closely approximate veins have been largely worked, and where we find that only particular strata of the limestone formation have been productive, the prospects for the future are much darkened by the great activity of the last two centuries.

B.—Among the lead mines occurring in the *slaty rocks* I will take a *northern group*, including the Isle of Man, the Lake District, and Lead Hills and Wanlock Head in Scotland, where the lower Silurian

* These amounts for 1871 have since that year suffered a *material decrease.*

strata have, with a moderate number of trials, produced several very important and lasting mines. Perhaps nowhere are the phenomena more varied and fraught with greater value than in the Isle of Man, where, amid rocks of clay-slate and more massive—somewhat gritty—beds, the old greywackè, lodes coursing east and west, as at the Foxdale mines, and others north and south, as the Laxey, are equally productive in a grand display of lead ores rich in silver. But the characters of these two lodes are otherwise almost as different as their directions, and especially when that of Foxdale shows the granite sometimes in one, sometimes in the other wall, and at length, in the deeper levels, nothing but granite country on both sides. The Bradda lode, producing both lead and copper ores, at the south-west corner of the island, is the noblest surface exhibition of a mineral vein to be seen in Europe. The length of good orey ground on some of these best lodes, their occasional great breadth—up to 20 and even 40 feet at Foxdale, and even 70 feet at Bradda,—their persistency in depth—as much as 235 fathoms below adit at Laxey,—and the considerable area likely from analogy to yield similar treasures, render it probable that a handsome production may long be expected from Manx soil.

Shropshire.—A similar isolated portion of this county, lying south of Shrewsbury, and to the east of the prominent geological feature of the quartzose crest of the Stiperstones, has long been noted for a series of east and west running veins, several of which are at present yielding very large amounts of *lead ore.* Among these the more remarkable are

the Snailbeach, the Tankerville, and the Roman Gravels, whilst several others give indications of future prosperity.

Cardiganshire and Montgomeryshire. — The hilly ranges, extending from Rhayader and Llanidloes to the sea by Aberystwith and the mouth of the Dovey, consist of a contorted mass of lower Silurian clay-slates, sometimes passing into sandstones, at others into thicker beds of argillaceous rock. They are intersected by very numerous east and west lodes of generally moderate dimensions, but which in some instances attain a thickness of 20 or even 30 feet, and may be traced for many miles over the open grass-covered mountain. Their composition, excepting in the usual character of long ranges of sterility interrupting the orey portions, is comparatively uniform, a little copper pyrites, mostly in the shallower levels, zinc-blende in certain mines, quartz in moderate abundance, iron pyrites and calcite rarely, being the only minerals associated with the lead ore, except where, on the eastern side of the district in several cases, witherite and barytes are added to the list. The absence of cross veins, in other respects a remarkable feature, may be one cause of the paucity of different minerals. To the advantages of easy ground, the moderate amount of underground springs, and the facility of applying water power for the machinery, may be ascribed in great part the profitable results which have attended the opening of many new as well as old mines within the last thirty years. And it should not be forgotten, that the highly

argentiferous character of the galena of some of the mines (twenty to thirty ounces to the ton of lead), gives at once a greatly enhanced value over what might be expected by one conversant only with simple lead ores. Some of the older mines, it is true, have been showing symptoms of decadence, and the almost proverbial glories of Goginau and the Lisburne mines and Cwm-ystwyth, have been outshone of late by the effulgence of the Van mine, near Llanidloes, with its 500 or 600 tons of ore per month; but none of them have as yet been worked to any great depth, 60 to 120 fathoms being commonly the limit, so that a small amount of capital expended in trying greater depth or horizontal extension in many of the long-worked mines may fairly be expected to open out good production in the future.

Devon and Cornwall.—In the slaty (killas) rocks of these counties lead-bearing veins have from time to time been found, which take an east and west course, like those of tin and copper. In the last generation some of these were worked in the district of Newlyn, north of Truro, and more recently one (West Chiverton) has attained a very notable degree of productiveness. But by far the greater part of the mines which have become famous in these two counties for the production of lead ores—mostly containing from thirty to sixty ounces of silver to the ton of lead—have been opened on cross veins, which successively slice through the country, at intervals all the way from near Exeter down to the south-west coast. Of these, the more notable, as giving rise to productive adventure, are,

beginning on the east, the Frank Mills and Exmouth, near Hennock, coursing up the valley of the Teign; 2nd, Wheal Betsy, north of Tavistock; 3rd, the Tamar, or Beer Alston mines, several parallel lodes, one of which, in South Hoo, was worked with success 250 fathoms deep; 4th, Red Moor, or the Callington mines; 5th, the Menheniot group, Wheal Mary Ann, lately working at 300 fathoms in depth, Trelawny, &c.; 6th, Herodsfoot, south-west of Liskeard; 7th, East Wheal Rose, near Newlyn, in its day perhaps the most profitable mine in Europe; 8th, Garras, near Truro; 9th, the Penrose group of several lodes near Helston, not now in working, besides sundry other cases, in which the cross courses have yielded small amounts of lead ore. The beauty of the veinstones, their general richness in silver, the variety and fine crystallization of the minerals found in them, all claim attention; but I can in a brief article like the present only refer to the fluors of the old Beer Alston mines and those of Menheniot, the delicate calcites, the barytes, and the pseudomorphous quartz of the latter group, with the splendid bournonites and tetrahedrites of the Herodsfoot. Nor must I omit to notice another fact, viz. that these lodes, making generally but little show at surface, have been worked at a horizontal distance from visible granite much beyond that belt of border ground which is most favourable to tin and copper lodes; and thus a large field, especially in Eastern Cornwall, may be pronounced fairly open to the reasonable expectation of meeting with similar sources of wealth. For confirmation of this opinion, it may

be stated that at the time of the Geological Survey by De la Beche (Report, 1839), nothing of value was known to exist in Menheniot, whilst the ores raised* from—

Wheal Trelawny, April 1, 1844, to Nov. 26, 1868, realized	£ 464,981
Wheal Mary Ann, May 1, 1846, to Sept. 30, 1868	454,788
Ludcott and Wheal Wrey, 1852 to 1865 ..	122,686
	£1,042,455

Over a million was in a few years produced from three of the so recently discovered mines, out of which about one-eighth was clear profit.

C.—Mines of lead *in granite*, although not rare abroad, are often considered at home so out of place that I may mention three remarkable examples, viz. Strontian, in north-west Scotland; Luganure, a series of fine mines in the county Wicklow, and the noble lode of Old Foxdale, in the Isle of Man, walled in, in its deeper levels, entirely by a bright-looking granite, and appearing to promise below the 140-fathom level a continuation of the courses of silvery ore which have yielded large profits above.

Copper Mines.

In some few cases the ores of copper may be met with near the surface of the ground, and thus seem to have attracted the attention of men even of the stone-hammer period, as may be seen in the old pits at

* W. J. Henwood, Cornwall Geol. Trans., viii. p. 719.

"Copper Hill," Cwm-ystwyth. More generally, and almost always in our south-western counties, the copper minerals have been, *in situ*, subject to chemical change, resulting in the disappearance of most of them from the shallow parts of the veins, down to a depth of from 20 to 60 or 80 fathoms; nay, so strong is the belief that valuable bodies of copper ore may occur beneath a great depth of the ferruginous cap of altered material, the *gossan*, that I have known a gallant band of adventurers persevere during some sixteen years, at West Sharp Tor, near Liskeard, to a depth of above 150 fathoms, bearing bravely a charge of tens of thousands of pounds, in pursuit of the ore which ought to underlie the gossan. Hence, indeed, the fact of the recent origin of copper mining of any importance amongst us, many of the veins, from which the ores of this metal have been so largely wrought in the last and the present century, having been explored by the ancients for tin, and the copper ores having been encountered only when the works exceeded 40 or 50 fathoms in depth.

In Cornwalli and Devon, a tract of country of about 80 miles in length by 8 to 20 miles in width includes all but a few stragglers of the copper-bearing lodes. It needs volumes* to tell of their multifarious characters and mineral contents, and occupies years and years of toil and study to get familiarized to their variableness, and to form opinions of any weight upon their value and promise. A few, however, of the most

* See De la Beche, Report, 1839; and Henwood, Trans. Cornwall Geol. Soc., v. and VIII.

notable characteristics may be briefly put as follows. The lodes course or strike most frequently from W.S.W. to E.N.E.; certain veins, of which several occur in a special district, and termed *caunters*, take an E.S.E. bearing; whilst in the extreme western parish of St. Just, an exceptional group of them approximate to the direction of the magnetic meridian, and are noted for particularly rich ores. These copper and tin-bearing lodes occupy the outskirts of some eight bosses, or hilly protrusions of granite, rising from amid the general country of slate, and are seldom observable as ore-bearing in any quantity at a greater distance than three miles from the edge of that crystalline rock. A strong prejudice long existed against the probability of valuable repositories of copper ore being found in the granite, but the abundant profits made at Wheal Damsel, Wheal Jewel, Tresavean, Wheal Buller, West Basset, and South Caradon, have effectually dissipated such a view. Among these Tresavean, in little more than ten years, from the beginning of 1828 to October 1838, yielded from a single lode copper ores which realized 770,338*l.*, of which nearly the half was profit; and South Caradon in a period of thirty years produced ores which sold for 1,001,536*l.** When we pass to those mines which have been worked partly in the one and partly in the other rock, and to those which have so far been explored in the killas alone, we come to a legion of lodes, a full appreciation of which

* My friend, Mr. J. A. Phillips, has contributed to another volume information on the statistics and nature of the copper ores, to which I may here refer the reader.

can only be obtained from the statistics annually compiled by Mr. R. Hunt, F.R.S., and from detailed maps of the several districts, such as those published by R. Symons, of Truro. I may enumerate, for example, within a belt of nine miles wide of strata, from Gwennap to Cligga Head, about forty of these parallel veins, including those of tin with those which have been looked on as chiefly copper veins, important enough to be entered on the Ordnance Map; whilst a large scale may show, with the side lodes and "branches," an aggregate of nearly double the number.

Let no one be misled, and imagine therefore that the rocky area is full of metallic ores, simply to be dug for. The first lesson to be learned in connection with these lodes is the very partial distribution of the valuable mineral, uncertain and discontinuous both in length and depth; and a second, that their breadth between the walls, commonly two or three feet, and seldom exceeding ten or twelve feet, is often reduced to a vein of an inch or two, or to a mere thread of rock-parting, which the most experienced miner will hardly recognize. Some few instances offer a much greater thickness, as, for example, the Devon Great Consols lode, sometimes 30 or 40 feet in breadth; the West Sharp Tor (unfortunately all poor), above 50 feet; and the fine courses of ore in the shallower parts of the High-burrow lode at Tincroft, 20 to 40 feet. And just as the public should be cautioned against a misunderstanding of the term of "a copper lode," so also should they be guarded against the crude notion of the country being now, by reason of its numerous mines, fairly

"worked out"; or that the extraction of heavy amounts of ore from a given vein is inconsistent with finding other important bodies deeper, farther, or in a parallel position, and at but a small distance.

The vast wealth rapidly won from some of the copper mines in the killas may be illustrated by the "Great Consolidated Mines" of Gwennap, which in twenty-one years (1819–40) sold ores for the sum of 2,254,485*l*., of which 480,156*l*. was divided as profit; and by the Devon Great Consols, where in a like period of time (1845–65) the total amount realized was 2,529,659*l*., of which 991,930*l*. was clear gain, still leaving the mine in a vigorous and highly productive condition.

I commenced this article by deploring the unlooked-for and amazing decadence of our great copper-mining industry. In part this is due to the fact of copper ores having given place in depth to tin in certain mines, whilst some other reasons which may be assigned for it will be discussed in a subsequent paragraph; and I may here dwell upon the great number of unexplored lodes, and the extent of favourable ground still to be tested within the proved cupriferous territory. We must not suppose that the working of a copper mine to the *finale* of a "winding up" is at all to be compared with the exhaustion of a colliery or of a gold digging. More fairly may it be considered a mishap which interrupts for a time the successive trials upon, and working of, a whole series of points at different depths. Let the price of the metal rise, and at once a number of places, abandoned perhaps for years, may

be opened with advantage, or at least with good prospects, which before that change had no chance of success. It is true that the depth to which many of our mines have penetrated, and the plentiful springs which have to be baffled by constant pumping, are a dead weight against us in the struggle of competition; but it is by no means improbable that when some of these disadvantages or a certain degree of poverty beset a few of the foreign mines, our now limited numbers may again be increased. Years have gone by without any startling discovery having been made, and the value of ores raised in these two counties has sunk from 1,230,000*l.* in 1856 to 236,436*l.* in 1873; but we may depend upon it, that unless all mining adventure be paralyzed by malpractices like those of the Pacific coast, a find like that of Wheal Maria, in 1845, would again invigorate and perhaps give years of success to our western mines.

The mining districts of the north of England are not without occasional examples of copper-bearing deposits; the group of small but economically worked veins of Coniston, and the curious lead and copper lodes of the Caldbeck Fells, both in the Lake District, still yield copper ores on a considerable scale. Alderley Edge, in Cheshire, is noted for a large production from ores of very low percentage, which occur disseminated in a band of white sandstones of the New Red sandstone series; and traces of the same kind of occurrence, where the ores are mostly the green and blue carbonates, have been observed and partially tested at sundry other points in

the same county. The Duke of Devonshire's strange narrow "pipe" of copper ore, which pierced almost vertically downwards among the highly contorted limestone beds of Ecton, in North Staffordshire, and which so long ago as 1778 * was 200 fathoms deep, and for years a perfect treasure house, is now idle. But the Parys and Mona mines, first opened about 1768 on a marvellous body of ore at Amlwch, in Anglesea, are working to this day, and form one of the most curious industrial scenes in the country. The vast masses of copper pyrites intercalated in the clay-slates of the district, which used to be raised from the grand *open-casts* by degrees excavated there, are phenomena of the past; but important quantities have continued to be produced by the deeper works of regular mining and by the cementation process, or precipitation of the metal from the waters of the mine.

When we look across the Channel to Ireland, we have, first, the range of mines of the Ovoca, raising but little at present of actual copper ore, but since 1840 productive of very telling amounts of slightly cupriferous iron pyrites, only of late overshadowed by the gigantic importation of a very similar mineral from the south of Spain and Portugal.

But the south and south-west of Ireland contain large areas remarkable for the occurrence of this metal. Knockmahon, in county Waterford, and Berehaven, in county Cork, have proved themselves two of the most profitable mines of the century: and although,

* Pryce, 'Mineralogia Cornubiensis,' p. 81.

in the first case, several of the lodes have been worked down into very poor ground, and in the second a depth of more than 250 fathoms has been attained, there are reasons for expecting continued prosperity. Moreover, the slaty regions ranging from Cork down to the Mizen Head, and farther north, including the strike of the Berehaven beds themselves, are remarkable for an exhibition at very many different points of beautiful ores of high percentage.* No great measure of success has yet attended the workings at most of these localities in West Cork; but with such an example as Berehaven, and the perseverance which, at Ballycumisk, has carried workings down to 222 fathoms, the temptation, when a good price rewards the efforts of the copper miner, to re-open and systematically to extend some of these mines, is certain to induce further enterprise.

TIN MINES.

Towards the latter end of the last century, statisticians, when they looked back, were amazed to observe that the annual amount of metallic tin produced by our western mines had been doubled in about sixty years, the annual average about 1778 being 3000 tons. At the same time it was held, by so well-informed a writer as Dr. Pryce, that "tin very seldom continues rich and worth the working beyond 50 fathoms deep; and it is absolutely certain that copper is not often wrought in great abundance till past that depth to 100 fathoms or more."

* Particularly *Bornite*, or "horse-flesh" ore, and copper glance.

Now that, after nearly one hundred years, again we cast a glimpse with "reverted eye" on the results of experience, during a period so rife with mechanical appliances, we note that the steady increase of output has brought the production of our two tin counties, Cornwall and Devon, up to 10,000 tons, the equivalent of near 15,000 tons of the dressed ore or "black tin." At the same time, the views as to the occurrence of this metallic ore have been so enlarged, as to require special notice even in so brief a sketch as the present.

A strange contrast is presented on turning from the numerous species of ores of coppér to the single mineral, the *cassiterite* or binoxide of tin, from which the metal is obtained; and yet is this single kind apt to occur in so many varieties of aggregation and of colour, as to form a test for the sharpness of the miner's eye and judgment. It is in fact often the case that large piles of valuable *tin-stuff* will show nothing that can be recognized by the unassisted eye, although it has happened often enough that very visible and telling portions of this ore have been overlooked by men otherwise well versed in the "metallick art."

The extent of country occupied by the tin lodes may be given as some twenty miles more in length than the copper district, for it includes also the whole width of Dartmoor. In some instances, and in particular in the heart of the granite bosses, the lodes carry tin without copper, as there are also some cases in which copper lodes have shown no observable quantity of tin. But in the greater number of these

repositories we find more or less of a commingling of the minerals of the two metals, sometimes confusedly in the same mass, sometimes in different divisions of the vein at the same horizon, at other times at different regions in depth. It is notorious that the "old men" have worked the "backs" of many lodes of tin which have afterwards in depth done well as copper mines; but it is only during the last few years that the extraordinary transmutation of some of our best copper mines into tin mines has changed the face of mining in the Redruth and Camborne districts.

Thus the fine run of lodes upon which the mines of Dolcoath, Cook's Kitchen, Tincroft, and Carn Brea,* have been so long opened, have of late years—as the excavations descend from 200 towards 300 fathoms in depth—gradually diminished their supplies of copper ores, but furnish enormous quantities of tin. Dolcoath, of which there was a tradition at the end of the last century that it had already yielded two millions of pounds' worth, mostly in copper ores, produced in the one year, 1816, copper ore to the value of 66,839*l.*; whilst for the year 1871 it figures in the statistics as producer of 1170 tons of tin ore, worth 95,373*l.*, while the copper ore is almost *nil*. In January 1873 I had the opportunity, under the hospitable guidance of Captain Thomas, of satisfying myself that it was precisely the same lode which, down to about the 160-fathom level, and with a width of from 10 feet to 20 feet, was so rich in copper, and which now, from the 190-fathom

* These four mines produced in 1871 tin ore to the amount of 221,595*l.*

level to the 312 (or 344 fathoms from surface), and passing through granite alone, has yielded tin only. The shallowest workings at present being at the 190, the principal operations are going forward at and below the level of 300 fathoms from the surface, the solid caply lode attaining a breadth of from 8 feet to 12 feet, including such branches of rich tinstone as to promise a long continuance of successful working.

Whilst in these several notable instances, to which I may add Levant and Botallack mines, both of which have yielded very large profits, it is curious to observe how the same lodes have borne tin almost exclusively in the granite, and copper ores on passing from that rock into the schists, I must not omit to remark how, in certain tracts at least, the schist or killas is thoroughly the "country" of the tin-bearing veins. Thus among our best tin mines, and down in the lists for the annual production of large quantities, we have Wheal Vor, Penhalls, Wheal Kitty, Polberro, Drakewalls, and the Charlestown United, in all which the containing rock is killas alone, although subject to the limitation pointed out above, of being within a moderate distance of the edge of the granite.

The statistics of the Mining Record Office give us a total for 1873 of 182 mines in Cornwall and eleven in Devonshire, as producing, with a few stream works, 14,837 tons, the money value of which, as ore, is upwards of a million. And when the question arises, whether such a production can be increased or even kept up to its *present* standard, we are obliged to bear

in mind that it depends upon a number of contingencies, for prophesying on which we have no competent authorities. The supplies of tin from the East India Islands and from Australia, the price, unfortunately so variable, at which the metal can be sold, the cost of coal, iron, timber, and human labour, are obviously the main items, upon a favourable concurrence of which we must depend for the successful continuation of tin mining in this country. As regards the opening of new mines to replace those which may be worked so deep or become so poor as to be unprofitable, I for my part, after a long experience of the unexpected places and circumstances in which fresh enterprise has led to good results, entertain sanguine expectation that, what with the re-opening of lodes already known, and here and there a new discovery, our tin production may go on for centuries, if we only get fair play.

Mines of Zinc, Antimony, and Manganese.

The ores of Zinc, whether the sulphide (blende) or the carbonate or hydro-silicate (calamine), are so commonly associated with those of copper and lead, that the workings are not often separate, and the zinc minerals are mostly raised from mines in which the other ores are the more important product. A partial exception might be made of Farnberry mine in Alston Moor, where beautiful calamine used to be raised, and of some few Welsh and English mines, generally in the lead districts, where the production of the higher-priced lead ore is of very trifling amount. Few lead mines like to acknowledge that they place much re-

liance on blende, or "jack," as it is commonly termed, until they have got high enough up among the scale of producers to approach Minera, Talargoch, Van, or the Great Laxey, which, raising this mineral by the thousands of tons (Laxey, 5370 tons in 1873), thereby obtain an important portion of their returns.

In the production of these ores, however, the British Islands only play a very subordinate part, nor does it appear likely that anything will occur to enable us to approach at all near to the yield of the Prussian or the Belgian works.

As far as I am aware, no ores of ANTIMONY appear to be raised in the United Kingdom, although in several little mines in the parish of Endellion, near Padstow, again near the Tamar, at Leigh, &c., and on the hills south-west of Conway, they used to be worked on a small scale.

MANGANESE ores were raised during the first third of the present century on a large scale, more particularly in Devonshire and East Cornwall. The deposits, as usual with the oxides of this metal, were of very irregular form, and so shallow as to admit of being worked either open or with very little machinery. In 1835–39 it was estimated that about 5000 tons were annually raised from the district named, whilst small quantities were also obtained from North Wales, where it occurs in numerous localities. All the English mining was brought to a standstill by the market being thrown open to the ores of Germany, and they in their turn have nearly been snuffed out by those of Southern Spain. A partial revivifi-

cation of our western mines has been in some measure effected by the discovery of a rich deposit in Devonshire, yielding, at Chillerton and Hogstor, 8254 tons of the ore in 1873.

Iron Mines.

It would be inconsistent with adherence to narrow limits to attempt to describe even the main features of the long list of mines which give Great Britain (1873) its 15½ millions of tons of iron ore, valued as worth above 7 millions of pounds sterling at the pit's mouth. A very large proportion of these ores, 5,000,000 tons, are of the class of iron-*stone*, alternating with the seams of coal and other strata in the coal measures, and worked therefore in many instances similarly to or in connection with the coals. Of late years these old-established materials of the manufacture of iron have become scarcer, and the enormously increased demand has had to be supplied from the strata of the secondary formations, the rust-coloured hydrous peroxides of which had, hundreds of years ago, already attracted attention. A thoroughly new application is that of the greenish grey stone of the "marlstone" of the lias in Yorkshire. This great branch of the iron trade may be said to have arisen about the year 1848, and the produce in 1873 from the lias of Cleveland, and the oolites of Yorkshire, Lincolnshire, Northamptonshire, and Wiltshire, amounted to no less than 7,600,000 tons, of which above 5½ millions were from the marvellous beds of Cleveland, in the North Riding.

Thirdly comes the division of the hæmatite ores, important for the part which they play in admixture with the poorer qualities of the first two divisions, as well as for the production *per se* of special kinds of pig and manufactured iron, particularly those suited to the Bessemer processes. A wonderful increase has been made in this category also, the amount raised in 1873 being 2½ million tons, including a small quantity of spathose ore, or chalybite. The two former divisions, giving the great bulk of the ores of low percentage, may, as constituents of the regular strata, be calculated upon, and, with due allowances, be made the subject of estimates to extend over years. But the third—that of the higher percentages—introduces at once all the "glorious uncertainty" of mining, whether we take the lodes of red and brown ore coursing in definite directions through the granite and older schistose rocks, as in Cornwall, the Lake District, and the Isle of Man, or those anomalous yet most important deposits, which have conferred a fabulous value on comparatively small patches of the carboniferous limestone, at Cleator in Cumberland, and Ulverstone in Furness. These two districts, indeed, have of late years produced upwards of two millions of tons per annum of ore, partly hard, mamillated, or reniform, with concentric layers, some of them fibrous; others as hard as quartz; and partly soft and unctuous "puddling ore," admitting of excavation with the greatest facility. For a thickness of many yards these treasures are often overlaid by the superficial crust "pinnel" of sands and clays, containing boulders,

and, as the surface tells no tale, the boring rod is the constant adjunct of the provident ironmaster. But so totally irregular and different is their figure, that the boring-tool may readily pass at a few inches from a mass worth 100,000*l.*, without discovering a trace of it; and almost the only general inferences to be deduced are, that trials must be multiplied, and that the *nidus* in which the ore is now found seems to have been eroded by long-continued water action.

It further appears probable, that the deposition of the iron ore has taken place in connection with that of the lower beds of red sandstone, at or after the great disturbance which attended the close of the carboniferous period, and it is clear that a re-arrangement of the deposited material and crystallization of red ore (specular iron), and of sundry other minerals, must have continued through a length of time.

The drain upon these resources is tremendous, knowing as we do how suddenly they may "cut out;" but there is unflagging search for new deposits; and the discovery recently made at Stank by the Barrow Company, showing that the same ore may underlie a great thickness of black shale resting on the limestone, adds a novel interest and a large acreage to the tract, in which there is fair reason to expect successful results.

Quite of a different character, although, I opine, of very similar origin, are the *churns* or underground deposits of brown ore, found in most irregular cavities in the upper strata of the carboniferous limestone of Dean Forest. The flanks of the Mendip Hills, and the

southern lip of the South Welsh coal-field, at the great Garth and near Llantrissant, yield both red and brown ores (hæmatites), under circumstances which point to the same mode of action, though differing perhaps a little in geological date.

I must not omit, even in so brief a summary, to congratulate the sister island on the important quantity (above 134,622 tons in 1873) of iron ores now raising, the major part of them brown ores, from beneath the beds of basalt in Antrim, offering at the same time a curious geological problem, and, as it would appear, a durable fount of employment and wealth.

When we look south-west to the lodes which, as cross courses, range north and south, and are not unfrequent near St. Austell and Bodmin, we find the dimensions such as to be incompatible with the large output of the northern mines. Some of them are of good red ore (the anhydrous peroxide); others of the brown kind; and the lode at Restormel, near Lostwithiel, is remarkable for the great variety of mineral species associated with this latter ore. A few instances of east and west lodes yielding brown "hæmatites" should not be overlooked, especially the curious series of veins, in great part unworked, which range for a distance of 30 miles from near Ilfracombe, through Exmoor to the Brendon Hill, in which latter the Ebbw Vale Iron Company has opened extensive mines, yielding good chalybite (spathose ore or carbonate) beneath the brown *chapeau de fer*. At length, too, after many years of alternation of inefficient workings

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and long fits of torpor, the great lode of Perran, near Truro, taking a course quite unusual on that side of Cornwall, E.S.E. and W.N.W., has been commenced upon on a suitable scale. I brought its chief characters under the notice of the Royal Geological Society of Cornwall some years ago,* and at different times devoted days to introducing it to the notice of iron-masters, all these attempts being attended with little success, until the present association, having brought a railway branch close up to the scene of action, will soon put to the test the question whether the rich brown ore above and the chalybite below will be found so to outweigh the "*spars*" and "*killas*" sure to occur in large portions of the lode, as under a vigorous system to give satisfactory results.

Methods of Working.

The chief features of the ordering of the excavations of extensive mines are comparatively new. Shafts have, of course, wherever deep mining has been attempted, been sunk at intervals along the line of the lode; and whether they should be *inclined*, following downwards the "underlie" of the lode, or vertical, passing down through *dead* ground, and having access by means of *cross-cuts* to the vein at 10, 12, or 15 fathoms apart—is a question differently answered according to the habit and the natural conditions of different districts. Where, as in most of our English mines, and in those of Saxony, the lodes are of mode-

* W. W. Smyth on the "Perran Iron Lode," Trans. R. Geol. Soc., Cornwall, VII.

rate size, and the rock pretty firm, it is usual, with a view to more rapid exploration, to sink most of the shafts *in* the lode, or with it; but on attaining a certain degree of success, to supplement them by a perpendicular shaft, intersecting the lode at a suitable depth, and greatly facilitating the employment of the best machinery for the deep operations. I do not wish to be personal, and abstain therefore from mentioning the names of British mines which I have seen gradually languish and expire for want of a good shaft. There comes, of course, a time in such a case when everyone can see what is the disease, but when it is too late to undertake the cure. When a mine only slightly feels the pressure of its depth, and whilst its dividends are good, then is obviously the moment for due foresight to be exercised in beginning at a well-chosen point the sinking of such a *downright* as shall best suit the pumping of the water, the winding of the *stuff*, and the lifting of the miners from their toilsome labour. "There is a tide in the affairs" of mines, as of men, and if not taken at the full, the remainder of the history is simply more or less rapid decay.

In the early part of the eighteenth century, and in some districts up almost to the present time, the orey ground was worked away between the shafts by ranges of *bottom* or under-hand *stopes*, the water from above running down over the successive steps of rock to the deepest point of the shaft, the *sump;* and the inconvenience occurring at once, that if the lode contained *attle* or refuse, this had to be sent up the shaft, or to be lodged on stages, or *stulls*, of timber. Now-a-days it is

the almost universal arrangement that levels (or drifts) should be opened at intervals of from ten to twenty fathoms, and conjoined, wherever the necessities of ventilation or a chance of favourable exploration point out the spot, by *winzes* or intermediate shafts, large enough to serve for a windlass or to be fitted with a ladder road. Thus the extent of the lode is cut up into a series of rectangles, in which, for the most part, the further excavation is effected by *back* or over-hand *stopes*, the men standing on the stone which they break down to attack the rock overhead, and thus working gradually upward. This method, *par gradins renversés*, very superior in economy as it generally is, must nevertheless in some cases of very precious ores or of large and jointed, and therefore dangerous lodes, or of specially hard material, still give place to the older system, *par gradins droits*, although in our own day the men ought not to be incommoded by bottom water, and by hand labour with windlasses or tackles, as we see by old drawings was so commonly the case a hundred years since.*

The pushing forward of these shafts and levels well ahead of the stopes, headings, or pitches from which the ore is being broken away, is one of the points in which good management comes most prominently

* See the section of Bullengarden (part of Dolcoath), Pryce, 'Min. Corn.' p. 172.

Mr. W. J. Henwood has pointed out (Cornwall Geol. Trans., VIII.) the probability of its having been the ingenious Raspe, of Hanover, the compiler of 'Baron Münchausen,' who first, in 1782–3, introduced this modification, already common in the Harz, into Cornwall.

forward. The constant advancement of exploratory feelers, the so-called *tut-work*, is, in fact, the very life of the future mine, and when we see it stopped, or even unduly checked, we may feel assured that the management is either incompetent or dishonest, or that with Oriental fatalism it has made up its mind that it is to die.

Hardly two hundred years have elapsed since the whole of these operations were performed by hand labour with the pick or the hammer and gad; but, at the beginning of the eighteenth century, the employment of gunpowder for blasting came commonly into play, and it soon became a matter of wonder how really hard ground could have been broken without it. Up to our time the modifications made have left the principle of the process untouched, but in several particulars have rendered it safer and more efficacious. Thus the substitution of cast steel for iron shanks to borers, which has been very rapidly brought in since 1851, and the use of bronze and copper for parts of the apparatus likely to strike fire with hard rock, and thus to cause premature explosion, have undoubtedly been most valuable. The firing of the charges by Bickford's safety fuze, and, for heavy blasts, by electricity, has been a great safeguard against the numerous accidents which, years ago, were thought to be inseparable from mining. I am, however, bound to acknowledge the freedom from casualties which attends large bodies of skilled and careful men, when employing the older fashion. The Laxey men, for example, about four hundred of them underground, retain tena-

ciously the shooting needle, and the straw filled with fine powder, for igniting the charge, and have for many years enjoyed a happy immunity from accidents. The introduction of new explosive materials, until their properties are well understood, cannot but be attended with risk; yet guncotton, nitro-glycerine, somewhat unceremoniously "put down" by the Home Office, and several of its off-shoots, dynamite, &c., have been proved to be so effective, that they must perforce come into extensive application.

This daily and hourly business of breaking the rock is *the* great expense of mining. It may be well or ill-directed, and such direction may be the prime cause of success or failure; but, any way, it is the manual labour which forms the chief item of cost. Why not then, in a mechanical country, and in an age that is nothing if not rapid and inventive, substitute machinery for human hands in so simple an operation as the boring of a hole in the rock? The question could hardly be answered in a stout octavo volume. Hundreds of inventors have really attacked the problem, and war in every form has been proposed to be waged against this inorganic obstacle to progress. Many of them have undertaken to bore out tunnels boldly at once, to chip the rock bodily to pieces, to grind it down, to gouge it out. Others, and more numerously since the success of the grand Mont Cenis perforation, have been content to retain the enormous advantage of an explosive compound, but have employed drills mechanically driven to bore the holes for them. Some two dozen of these "drilling machines," or "power-jumpers," beginning

with the late Herr Schumann's at Freiberg, are in the field, and have been giving good results in experiment. True that Herr Döring's, applied to the hard deep tin lodes at Tincroft and Dolcoath, were, after a long trial, withdrawn; but at least four other varieties are being so tested in tunnel and mine work, and the diamond borer of M. Leschot has been taken up so vigorously by the company formed to work it, that the mining interest ought soon to be supplied with the requisite *data* of prime cost, maintenance, and progress made.

I can only glance cursorily at the mechanical appliances which follow the breaking of the ores. In mines of stratified mineral, where large quantities can be fully reckoned upon, traction by powerful horses, or even by engine power, is carried out as perfectly as in the coal mines; but in general the supply is too uncertain, and too limited from particular points, to admit of the introduction of what are theoretically the best methods. A great improvement has been the widening of the levels, and fitting them with tramways of edge-rails, as is now generally practised in the principal roadways of our metallic mines; but where the trials are more than ordinarily precarious, the old unsatisfactory wheelbarrow holds its own, and very often in places where it ought to be superseded.

In approaching the subject of drawing or winding the mineral in the shafts, we find, as before, that the prolific iron mines of the north, with their guides and cages, or well laid inclines and rapidly working engines, offer an admirable example, which is only very slowly and at a long interval followed by the

leading tin and copper and lead mines. The substitution, however, of better methods for the rough system of the dangerous single-link chain, and the loose kibble banging against the sides of the shaft, can only keep pace with the laying open of reasonably large bodies of mineral, and with the sinking of suitable shafts, as explained above.

The pumping of the water has, as regards the pit-work, undergone a great amelioration in the general use of the *plunger*, or force-pump, for all but the lower lift, a forward step which, commencing in Cornwall at the close of the last century, has for many years been general in nearly all our metallic mines. The several lifts too, formerly of only a few yards, are of from thirty to fifty fathoms in height, so that the working parts, *poles* and *clacks*, or valves, are, in a deep shaft, greatly reduced in number; the system being as of yore, that the "tye," or uppermost lift, takes its water from the "rose" next below, the rose from the "crown," the crown from the "lily," and so on to the bottom, or *sump*. Where the advantage of adequate water power is not enjoyed, the Cornish engine is almost universally applied to this purpose; and although much adverse criticism has been brought to bear on this doubtless ponderous machine, and its heavy first cost, the critics fail to show us in action other means of raising large bodies of water with equal economy. I would say nothing but good of the convenient direct double engine, placed at the bottom of shafts as much as a hundred fathoms deep, and plunging their water up to the surface; but such for obvious

reasons are not often applicable in metallic mines, and I would point to the Wallsend pit, on the Tyne, as a recent example of the successful application of a giant of the beam-engine species. At this well-known, but long-drowned colliery, whose name has, for many years past, been a delusion and snare to the coal-buying public, a Cornish engine, with 100-inch cylinder, built at Hayle, has within the last two years been completed, to pump, with 26-inch plungers, the feeder of water which was before kept by other engines. Three Cornish boilers were (in July 1873) sufficient to accomplish the work for which *seven* were needed before, the consumption of coal had been reduced to 3 lb. per horse-power per hour, and one man was easily attending to the firing, where two men had had to work very hard "to keep their boilers agate."

Alas! that, in conclusion, it should have to be confessed that few good and properly kept examples of this fine variety of engine are now to be seen in its native county. The *duty*, or work done, for a given weight of coal, is notably lower than it was twenty years ago; and the number of engines duly examined and "reported," smaller. It is an insufficient answer to aver that the coal is inferior to what it used to be, or that the agents of the mine can test the engine as well as a "reporter." The fact is too clear to the eye, at once on entering the engine house, that the spirit and pride which used, a quarter of a century ago, to actuate engineer, mine captain, and engine man, are broken down, or sleeping. The depression of poverty is no doubt, in some cases, a partial excuse,

in others the necessity for obeying the behests of penny-wise non-resident directors; but assuredly, with the increased price of coal swelling their cost, and amid the unfavourable critiques which have been provoked, it is time that both mine agents and engineers exerted themselves to wipe off, along with the dust and grease and rust, the reproach of actual retrogression.

I cannot omit to cast a glance upon the modes of ascent and descent, so fraught with importance to the health and lives of the men, as well as to the economy of their labour. The method in general use in collieries, by which the men are wound up or down the shaft by the rope worked by a hoisting engine, is but rarely employed in metallic mines, although the guided cage, often with "safety clutches" attached, is thus utilized in the hæmatite mines of the north, at Stonecroft lead mine, at Allenheads, and a few others. But the obstacles to its general introduction are mainly the varying angles of inclination of the shafts, and the distribution of the workmen at a number of different levels. It would also be incompatible with the very common use of single-link chains, and the rough condition of the shafts. The general method is to climb by a succession of ladders, of from three to five fathoms in length, the but or heel of each of which rests on the floor of a *sollar*, or platform, and protrudes through a small opening, the *man-hole*, in the sollar above. If the ladders are well placed, at an angle of 70° to 80°, and properly kept, the risk of accident is but small; yet when the depth of a mine exceeds, say, 150 fathoms, the wear and tear of the system, and the

loss of time expended in this unremunerative labour, have been shown over and over again to be a crying evil. An experienced hand will recognize the fact, that it is less fatiguing to climb 200 fathoms in one mine than 150 in another; and that it is not only the position and condition of the ladders, but the ventilation and the space of the footways that affect the question. Yet in spite of the simplicity of the principles of a good ladder road, we see them so often, and in unexpected places too, grossly neglected, and observe such a toleration of dirt, discomfort, and risk, as to suggest the idea that, if for the amending of the travelling ways alone, the late appointment of two Home Office inspectors may do a great service.

The mines of the Harz, at that time the deepest in the world, originated in 1834 the plan of raising the men by the *fahrkunst*, a pair of rods moved like those of a pump, alternately up and down, and so lifting a man, standing on a small stage, through a certain number of feet—the length of the *stroke*—to a position opposite to a similar stage on the other rod, to which he quickly steps, to be again lifted through the same number of feet. This contrivance, very widely used on the Continent, and in collieries as well as in metalliferous mines, was, under the name of the man-engine, first introduced into this country at Tresavean and the United Mines at Gwennap—both of them at present inactive—where they proved an inestimable benefit. A modification, consisting of a single rod, duly counterbalanced, and with its stages corresponding with fixed sollars in the side of the shaft, was

some years afterwards put in and worked by a water-wheel at Fowey Consols mines, and a similar arrangement has been adopted at half-a-dozen of the western mines, even in shafts with variable underlie. In every case it appears to have been recognized that the cost of the apparatus has been recouped in a very short period, that accidents have been very few, and that deep workings have been carried on by its aid which would otherwise have been abandoned. Why, it may be asked, is this great boon not more largely introduced in the deep mines? There is no satisfactory reply to give; but I can only point to what has already been said on the want of foresight in sinking good and sufficient shafts, and to the difficulty in commanding a couple of thousand pounds, which often besets the adventurers in a deep mine struggling against adversity.

Dressing of Ores.

The mechanical preparation by which the ores are separated from the various substances commingled in the lodes, and are thus rendered merchantable, is by no means an unimportant capping to the various operations which have to be conducted on the site of a mine. Simple as the processes may be which alone will accord with the "paying" of substances of low intrinsic value, such as iron ores, or which may alone be needed with certain minerals like the ores of copper, habitually taken by the smelters with a very low percentage,* the dressing of ores which require to

* The average produce of the Cornish copper ores is from $6\frac{1}{8}$ to 7.

be brought up to a high percentage, like lead and tin, and of those of high intrinsic value, as gold and silver, involves a great variety of machinery and processes. It is, in fact, such a matter of detail that it would be equally unfair to reader and to writer to attempt more, in my very narrow limits, than to refer to a few salient points of interest.

Roughly it may be said that the chief divisions of the subject are: firstly, the breaking up and comminution of the mixed vein-stuff; and next, the division, upon the basis of specific gravity, of the valuable from the worthless materials.

In the first, it is a maxim that vein-stuff should not be reduced below the size at which the particles of metallic mineral can be released from the adhering substance. Thus, for the generality of copper and lead ores, nothing equals the *crusher* or rolls with hard cast-iron shell, first introduced in our western counties about 1810–20; but, for the poorer classes of such ores, as also for tin and gold disseminated in small particles, a much finer reduction is needed, and the stamps come into play. For a still finer, impalpable powder sometimes required, as for amalgamation, and for "tin leavings," some kind of grinding machine, an "arrastra," or "pulverizer," is employed. Where the object is merely to break up large lumps into small, in lieu of hand "spalling" with a heavy sledge, Blake's "stone-breaker" is now in high repute; but with this, as with other comminuting apparatus, the caution is much needed that careful sorting or picking of various classes of ore should precede that general

mixing up which otherwise is sure to ensue, and to prolong and complicate and introduce certain loss into the succeeding processes.

The stamps are doubtless in some points of principle open to criticism as machines, yet nothing has yet been found to supersede them. Improved forms have been proposed, and the pneumatic stamps of Harvey and Co., at Hayle, do amazing work, one of their heads performing as much as six of the ordinary type. So, also, it appears do the heavy steam-hammer stamps of Lake Superior. The modern gold districts, too, of California, Colorado, and Australia, all boast the excellence of their peculiar variations; but whilst admitting the good features of some of the novelties, we still need twenty or thirty years steady pounding to give us all the *data* of the efficiency and durability of the machine as an element of economy.

All our English tin mines employ the stamping mills, with—according to scale—from 3 to 150 heads, each of the weight of from 300 to 800 lb. One mine only, Drakewalls, noted for its boldly crystallized tin, used to crush its ore with rolls; but this exception has passed away, and stamps alone are the order of the day.

Dr. Pryce, writing in 1778, quotes an old work, from which he gathers that the dressing of tin ore in Queen Elizabeth's time was "exceeding slovenly," and adds: "I am very sure, notwithstanding our present advance, we are yet at some distance from perfection in that art." Now, after the lapse of a century, I may repeat, *totidem verbis*, that judicious author's sentiment. The

art is, in fact, at present passing through a period of rapid transition, in which, irrespective of the pulverizing machines, the following features may be noticed.

For the separation of ore from refuse in fragments and rough grains, the sieve dipping into water and the brake jigging machine, or hotching tub (north), are being supplanted by the piston or plunger machines, taken from German models, but founded on a very similar plan to that applied by Mr. Petherick at Fowey Consols some forty years ago. The efficient *sizing* of the particles for the several jiggers, their working with very little manual labour, and the continuous action of some of the varieties, are great improvements over the old methods.

Among the numerous classes of inclined planes, *buddles*, *frames*, &c., on which, when in a fine state of subdivision, the various substances to be separated are set in motion with a stream of water, the old rectangular forms are giving way to the circular. The "round buddles," thirty years ago a novelty in a Welsh lead mine, are now at home throughout Europe, although sundry points in their construction and working require to be varied for different ores, and to be well attended to, if we would purchase their greater rapidity of action without paying for it in loss of mineral. Diameters differ, from 16 feet to 24 feet, and even to 50 feet at Wheal Owles, in St. Just. The proportion of the head to the body, and the velocity of feed, &c., are very various, and whilst the most usual are convex, the concave forms of Hundt and Borlase do good

service in certain cases. Similarly the fixed frames, for receiving only a thin covering of mineral, are much replaced in the last few years by rotating frames, in which a single slow revolution of six to twelve minutes perfectly cleans the head of the deposit. The percussion frame (*stoss-herd*), employed with such success in Hungary and Germany, has but rarely been duly tested in this country, although a pair of the continuous kind, Rittinger's invention, was erected, and worked admirably, by Mr. Plaminek, at the Clogau gold mine.

The nicety, judgment, and careful supervision necessary to success in these and the score of attendant manipulations, may be appreciated by the facts that several hundreds of workpeople have to be engaged on the dressing-floors of an extensive mine, and that an enormous proportion of refuse has to be got rid of to render duly clean a comparatively small amount of marketable ore. In many lead mines, from 20 to 40 tons of mixed mineral have to be treated in order to obtain a single ton of clean ore; nay, as much as 100 tons in the case of argentiferous slimes like those of Foxdale. And whilst in our tin mines a proportion of two of black tin* per cent. of the crude tin-stuff is to be obtained from the richer lodes, many of them yield not more than one part of clean black tin in a hundred, or even one part in two hundred, out of the total quantity which is subjected to so protracted and laborious a treatment.

* *Black tin* is the ore, oxide of tin, Cassiterite; *white tin* is the metal as produced by the smelter, and of which the former in ts purest state contains about 75 per cent.

COAL.

By A. Galletly (Curator of the Edinburgh Museum of Science and Art).

Although wood, peat, and coal furnish our most valuable kinds of fuel, yet the substances which either are, or might be used to produce artificial heat, are numerous. In tropical deserts camel's dung is carefully stored up to burn in fires, and all over India cow's dung is not less important as a fuel, showing that man, in spite of his pride, is sometimes beholden to apply despised things in curious ways. In the plains of South America dried thistle-stems, and in other countries where wood is scarce, the roots of herbaceous plants furnish the only available fuel. An oil lamp is almost the only source of the heat and light with which the Esquimaux can cheer themselves during the long Arctic winter, the ocean currents which carry such an abundant supply of driftwood to treeless Iceland conveying to their inclement regions but a scanty share.

Coal far surpasses all other substances in value and importance as a fuel; yet it appears to have come comparatively slowly into use, it being towards the end of the thirteenth century before it was much employed in London. In some parts of England, however, it had been burned in fires long before this, as it

is known to have been, to some extent, an article of household consumption by the Anglo-Saxons in the ninth century. There is evidence which appears to show that the Romans were not unacquainted with it, since coal cinders have been found among the ruins of buildings known to be Roman. Some of their stations were near the outcrops of coal seams, and a few years ago one of these near Wigan was discovered to be partially mined, and in such an unusual way that Professor Hull believed it to be Roman work. It is even probable that the ancient Britons knew something about coal, tools of flint and wood having been found in the outcrop or in partial excavations of one or two seams. In the sacred Scriptures the word "coal" occurs repeatedly, but there is little doubt that in every case wood charcoal is meant, although only on one occasion, namely in Psalm cxx., is this distinctly expressed. At one time it was the custom to use the name pit coal, and in London sea coal, to distinguish this mineral from charcoal or burnt wood.

For a long time after coal was introduced into the metropolis, a strong prejudice existed against it, and proclamations were issued forbidding its use during the sitting of Parliament, both by Edward I. and Elizabeth. As late as the middle of the seventeenth century the citizens of London are said to have petitioned Parliament against two nuisances, "Newcastle coals on account of their stench, &c.; and hops, in regard they would spoyle the taste of drinck and endanger the people." By this time, however, the supply of wood was beginning to fail, so that coal was *becoming* more and more indispensable, whatever

objections the Londoners of that day may have had to its smoke and stench. But those who live in remote inland districts will, even at the present time, easily understand that there were large tracts of the country to which, owing to the difficulties and expense of carriage, it was impracticable to convey coal for nearly two centuries after its great value as a fuel was well known.

The consumption of coal must have rapidly increased after the introduction of Watt's steam engine in 1769, which at the same time furnished the mine owner with a powerful aid towards increasing the supply. A little later, the construction of canals in central England furnished a new and cheap means of inland conveyance, and so facilitated its distribution. Other inventions and changes were soon to make new demands on our stores of fossil fuel, among which we may mention steam navigation, inaugurated by Symington in 1801; the introduction of gas-lighting in 1810, and finally the extension of our railway system. Our great national industries, benefiting by these changes, have gradually come to tax the yield of our coal fields to an enormous extent; and as among these the iron manufacture is by far the most important, I will glance at its history in relation to mineral fuel. A patent for the use of pit coal in making iron was taken out by one Simon Sturtevant as early as 1612, but he does not appear to have tried the process on the large scale. However, in 1618 Lord Dudley took up the task in earnest. He worked long and zealously, but spent all his means without surmounting the difficulties attending the introduction of coal, and

finally was imprisoned for debt. Charcoal accordingly continued to be used for smelting iron, till Abraham Darby tried pit coal again at Coalbrookdale in 1713. Not even yet was the innovation successful, because with the new fuel the make of English iron fell off, and did not rally till the introduction of coke about 1750. After this, however, the iron manufacture, and with it the consumption of coal, rapidly increased, especially since the introduction of the hot-blast process in 1830, which, although it reduced about one-half the relative quantity of coal used in proportion to the amount of iron made, nevertheless largely added to the yearly production of iron, so that more than one-fourth of all the coal raised in Great Britain, or nearly 34 million tons, are now required to supply the wants of our iron districts.

Mr. R. Hunt, in his 'Mineral Statistics' for the year 1873, published for the first time a table showing, as nearly as he could obtain them after laborious inquiry, the quantities of coal annually used in the leading industries of the country and in domestic consumption. From this we learn, that after that consumed in the making of iron, the next largest quantity, or 27,550,000 tons, is required for steam power in our manufactories; that no less than 9,500,000 tons are consumed in working our collieries and metalliferous mines (there being little doubt that no inconsiderable part of the colliery consumption is sheer waste); that the manufacture of pottery, bricks, glass, lime, and cement takes 3,450,000 tons; and that the great chemical industries, which include alkali making, soap boiling, *distilling*, sugar refining, the evaporation of salt-brine,

and several others, require another 3,217,200 tons. Further, that it takes as many as 6,560,000 tons to supply our gasworks, and of this quantity London and its suburbs—the population of the area taken being nearly four millions—consume about 1,720,000 tons, while Edinburgh and Leith, with an aggregate population of 242,000, require for the same purpose 75,000 tons. For domestic consumption, Mr. Hunt gives the annual consumption at scarcely 13 cwt. per head of the population, or only two-thirds of what was the generally accepted estimate before his recent inquiries into the matter. The entire table, slightly altered in arrangement, is as follows:—

	tons.
Total coal raised in the United Kingdom in 1873	127,016,747
Exported	12,712,222
Left for home consumption	114,304,525
Consumed in the manufacture of iron ..	35,119,709
„ in smelting other metals ..	763,607
„ by collieries and mines	9,500,000
„ on railways	3,790,000
„ in steam navigation	3,650,000
„ for steam power in manufactories	27,550,000
„ in gas making	6,560,000
„ in waterworks	650,000
„ in potteries, glass works, brick, lime, and cement kilns ..	3,450,000
„ in chemical works, and all other sundry manufactures	3,217,229
„ for domestic purposes	20,053,980
	114,304,525

It has been estimated that in the beginning of this century our annual output of coal did not exceed 10 million tons. Even as late as 1845 it seems to have been under 32 millions; but there were no reliable returns till 1854. Since then, however, accurate accounts of the quantities raised have been published every year by the Keeper of Mining Records. The largest produce in any single year was that of 1873, and the greatest falling off in the production, comparing one year with another, took place in 1874, which shows a decrease of about two million tons on the previous year. It is, of course, possible, and even likely, that this considerable decrease is partly owing to the introduction of more economical methods of burning coal, in which case it would be a hopeful sign; but no doubt it was mainly due to the depression of trade. This view is to some extent borne out by the fact that the production of pig-iron in 1874 was considerably less than it had been for some years previously, while at the same time the average quantity of coal used in smelting a ton of pig-iron was also, though but slightly, less. Comparing the figures given by Mr. Hunt for the last twenty years, we find that the consumption of coal in Great Britain has in the main increased at a very rapid rate, as the following table will show:—

		tons.
Raised in	1855	64,453,000
„	1860	84,043,000
„	1865	98,150,000
„	1870	110,431,000
„	1873	127,017,000
„	1874	125,068,000

Turning now to the natural history of coal, we find the celebrated American mineralogist Dana, in the earlier edition of his work, defining it as carbon with a small percentage of clay, and sometimes oxide of iron; often containing a large percentage of bitumen; as massive, black or brown in colour, dull to brilliant in lustre, and brittle or sectile; of a hardness varying between 1 and 2·5 of the mineral scale; and of a specific gravity varying from 1·2 to 1·75. Anthracite, he, of course, stated to be a non-bituminous variety. Probably this general definition of coal as a mineral would still have been deemed satisfactory enough, had not a couple of fierce quarrels about mineral leases given a somewhat unusual interest to the question, "What is coal?" In 1850 the proprietor of the estate of Torbanehill, near Bathgate, in Scotland, let certain minerals found on his lands, including coal, to a firm of coal-masters for a period of twenty-five years; but after only two of these had elapsed, he challenged the right of the lessees to work a comparatively thin seam of a mineral which they were raising and selling under the name of gas coal. A lengthened and costly litigation followed, the one side asserting that the mineral in question was a bituminous shale or at least not a coal, the other that it was a gas or cannel coal. The trial took place at Edinburgh in the summer of 1853, and lasted six days, during which seventy-six of the most eminent men of science in Great Britain were examined. The evidence was most conflicting, but the jury returned a verdict in favour of the lessees, deciding the question mainly on the ground of its

being coal in a popular or commercial sense, whatever it was scientifically. Referring to the evidence, the Lord President in his charge remarked, "When I have so many geologists on the one side who tell me that a thing is coal, and so many on the other side who tell me the opposite, I cannot say that I feel myself much wiser, or much farther advanced in the inquiry. And if I have an equal number of chemists of equal skill, and speaking with reasons that are equally convincing, with equal authority and equal contrariety, I think I should be in no better position; I might say the same of microscopists," &c. The case was carried by appeal to the House of Lords, and was ultimately settled by a kind of compromise. In 1860 another equally long and perhaps still more costly trial took place in Edinburgh respecting the validity of Mr. James Young's patent for manufacturing paraffin oil and paraffin from coal, in which the same question, viz. whether this Boghead mineral was a coal, was incidentally raised. But I only refer to this second trial, the result of which did not disturb the verdict of the first, to say that by it much information was brought to light on the composition and products of coal, without, however, bringing us much nearer to an accurate definition of the mineral itself. The other trial, or rather trials, for there were two, alluded to above, took place in Canada in 1852. They referred to a mineral known as Albert coal, or Albertite, which occurs at Hillsboro, Albert county, New Brunswick, in an almost vertical vein, from 1 to 16 feet thick, and appears to be since universally regarded by mineralo-

gists as a variety of asphaltum. In this litigation the jury in the first trial decided that the mineral was asphaltum; in the second, another jury decided that it was coal. Chemists had been summoned from all quarters, and the law expenses of the dispute amounted to 30,000 dollars.

Although not concerned here with a strictly scientific definition of coal, I have nevertheless referred to these trials to show how disputes leading to great trouble and expense may arise, from the impossibility of defining with precision what such a very common substance is. Generally speaking, however, it may be said that under the term coal is included any solid mineral substance infusible under its point of ignition, and containing sufficient carbon to allow of its continuous combustion in the fireplace of an ordinary grate. Those substances having too large a proportion of incombustible mineral matter to be classed as coal, and yet so far agreeing with this definition, generally owe their character to the coal which they contain. It is usually of black colour and stony consistency, and when heated in close vessels is converted into coke, with the escape of gases and liquid vapours. There is, however, an exception to this in the case of anthracite, which contains little or no volatile matter.

All coal is of vegetable origin, a fact which can be readily proved by examining a thin slice of any piece under the microscope, when the tissues of plants which form it will be usually though imperfectly seen, as in nearly every case these have been much altered during the process of fossilization. In most coals there are

two kinds of structure, the one called mineral charcoal, much of which is like charred wood, but much of it also is of a dense black texture, with scarcely a trace of vegetable tissue recognizable; the other composed of round cell-like bodies, which constitute the bituminous portion. The translucent brownish cells are said to be abundant in coal which is rich in elements producing oil, or gas of a highly illuminating power, according to the degree of heat employed in distilling it; on the other hand the black fibrous or coaly portion prevails, and these cells are far fewer in coal which yields little or no oil and only gas of poor quality. In recent years, the origin of the volatile or bituminous matter in many coals has been traced to the resinous spores of plants allied to club mosses and ferns. Some observers indeed think that the bulk of the substance of some coals is composed of these minute bodies. The plants which chiefly produced the spores found in coal, unlike the club mosses of the present day, which rarely grow to more than a few inches in height, were gigantic trees, as we see in the lepidodendra and other remains found in coal seams.

Coal is found in layers or strata, from 1 inch up to 30 or 40 feet in thickness, but such very thick masses are rather an accumulation of several seams, between which the usual intervening deposits of other matter have from some cause or other been thinned away. Seven or eight feet is perhaps the maximum thickness of single seams, and miners consider one which measures 5 feet as a thick bed, while seams much below

2 feet in thickness can rarely be profitably worked. Sandstone, shale, limestone, ironstone, and fireclay are the principal kinds of rock interstratified with coal. The seams, as a rule, are wonderfully uniform in thickness and quality over large areas; sometimes, however, they are anthracitic at one place and bituminous at another. Occasionally, again, a layer of coal is found to pass gradually into an ironstone, while the beds of rock immediately above and below it continue the same. With some few exceptions, the rocks in which true coal occurs belong to the upper palæozoic period, and are known as the carboniferous series. The coal seams are chiefly, but not solely, found in the upper division of the group called the coal measures. Coal from other geological formations, such as the Oolite, occurs only rarely in sufficient quantity to make it of much commercial importance, with the exception of the imperfectly mineralized kind known as brown coal, or lignite.

The vegetation of the carboniferous period grew in dense forests, and many of the plants, as already stated, were of gigantic size. It would appear that a warm and equable climate had then prevailed over a large portion of the globe, as, in the coal measures, fossil plants of the same species are very widely distributed. The prevailing opinion among geologists is, that in most cases coal seams were formed on the sites where the plants of which they are composed grew, and that therefore the underclay formed their soil. The forests seem to have grown and decayed on land but slightly elevated above the level of the sea; and after

a great thickness of vegetable matter had thus accumulated, the land slowly sank beneath the water. Over this, sand, mud, and other sediment were deposited, which in course of time through some movement became elevated above the sea to form the soil of another dense mass of vegetation, which after a longer or shorter period sank by depression as before. Sedimentary deposits of other substances then covered this new layer of decayed and decaying plants, and so the process went on, till the superincumbent strata produced pressure enough to convert, aided by other chemical changes, the vegetable pulp into coal.

In commercial language the number of kinds of coal is very numerous; as many, it is said, as seventy denominations of it being sent to London alone. Between many of these the difference in properties and quality is very trifling, and there are characters sufficiently definite, by which all coal found in the coal measures may be grouped into three leading kinds, thus:

I. Anthracite, non-bituminous;
II. Cannel coal, highly bituminous;
III. Household coal, less bituminous.

Or we may take only two principal kinds, namely, anthracite and bituminous coal. Brown coal, or lignite, is the product of a comparatively recent geological age, and will be referred to afterwards. It is well to keep in mind that bitumen does not exist ready formed in any coal, since none is to any appreciable extent dissolved by liquids, such as turpentine, which dissolve the bitumens; but most kinds, except anthracite, when distilled in close vessels yield pro-

ducts, although in very variable quantities, which resemble those obtained from native bitumen. Perhaps therefore it would be better to call such coals bituminiferous than bituminous.

Anthracite is more stony looking, more completely mineralized, and heavier than other kinds of coal. When pure it does not stain the fingers, is of a glossy black colour, though sometimes beautifully iridescent. It is difficult to kindle, but in burning gives off an intense heat with little or no smoke, and is principally consumed in smelting metals and raising steam. Anthracite never contains less than 80 per cent. of carbon, while some varieties of it consist almost wholly of that element. It is found largely in Wales and in the United States. *Cannel coal*, called also in Scotland parrot coal, receives the former name from its burning like a candle, and the latter from the crackling chattering noise it makes when thrown on a fire. Of all the varieties, it is usually the most earthy-looking and least like that used for household purposes. Some kinds of it, however, though rarely, are nearly as bright and shining as anthracite. Cannel coal is always compact, breaks sometimes with a slaty, though usually with a conchoidal, fracture, and some of the richer varieties are rather brown than black in colour. Like anthracite it does not soil the fingers, and both kinds are made into ornaments, such as beads, boxes, inkstands, and vases. The cannel coal, indeed, of some Scottish localities, can even be made into tables of considerable size, which, when polished, approach black marble in appearance. Other kinds, again, with

much the same composition, are totally unfit for such purposes, as they split up into pieces after being a short time exposed to the air. I have heard that at a time when cannel coal was little known, the Duke of Bridgewater, having found some by the side of his canal, had a set of dinner plates and other dishes made of it, invited a large party to his house, and after they had dined, the dishes were thrown on the fire, to the great amusement of the company. These, however, are more curious than useful applications of this substance, which is by far the most valuable kind of coal. It is now almost wholly employed to yield gas, but it has also been used as a source of paraffin oil, the former product being obtained when the coal is distilled at a high, the latter when at a comparatively low temperature. So great is the value of some cannel, as compared with other descriptions of coal, that the fine seam of it at Boghead, near Bathgate, already referred to, has sold as high as 4*l.* per ton, when good household coal was selling in the same locality at only 10*s.* It yields 15,000 cubic feet of gas per ton, of a high illuminating power, and is one of the richest gas coals known. This valuable seam is now nearly exhausted, but a few others in Scotland, such as that found at Methel, in Fife, are not far behind it in richness. It is scarcely necessary to say that other bituminous coals, besides cannel—some of the Newcastle kinds, for example—are used in the manufacture of gas, but their yield is usually inferior in quantity, always in quality. The chief English locality for cannel is at Wigan, but it is abundant in Scotland, and is also

found in North America. The third kind, or rather group of kinds, is known as *Ordinary*, or *Household, coal.* Most of its varieties, unlike either anthracite or cannel coal, are suitable for burning in common fires; but they are used for various purposes, and in the Newcastle district, for example, are classified as house, steam, coking, manufacturing, gas coal, and so on, according to the purpose for which any given kind is best adapted. The names given in commerce to the innumerable varieties, or rather qualities of ordinary bituminous coal, tell almost nothing as to their value or properties, except to those whose business it is to traffic in them. There are, however, certain physical characters by which they can generally be classed under one or the other of the three following varieties: 1, Caking; 2, Cherry; and 3, Splint coal. Caking coal has a shining resinous lustre, breaks readily into small irregular cubes, and, when burning, there exudes from it a black bituminous substance, so that many pieces form in the fire into a pasty mass. The liquid portion is readily decomposed by heat, and leaves a carbonaceous residue, or cake. Coke is chiefly made from this kind of coal. It is also valuable for domestic purposes, but requires frequent stirring. Cherry coal resembles the preceding in its external characters, but does not fuse in burning, and yields a coke in powder, or in the form of the original coal. Both varieties often closely agree in chemical composition, and both are also called "soft," from their being easily broken. They often occur together in the same bed, and pass into each

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other by insensible gradation. The principal beds of the Newcastle coal field are, however, composed of caking, and those found in Staffordshire of cherry coal. Splint, sometimes called slate coal, has a more distinctly bedded or laminated appearance than other kinds, breaks with an uneven and splintery fracture, and with so much difficulty, that it is often termed hard coal. It is not very easily kindled, does not alter its form in burning, and slowly consumes with much heat. From the fact that cherry, and especially splint coal, in burning, allow space for air to pass freely through the fire, they are called free burning coals. Splint coal, from its hardness, is usually obtained in larger pieces than other kinds, and is very common in Scotland.

Although not of much consequence in England, since it is only worked to a limited extent, and that chiefly at Bovey Tracey, in Devonshire, the substance known as brown coal or lignite is an important fuel in some European countries, and in other parts of the world. It is found in several formations newer than the carboniferous, but most largely in the Tertiary beds, and varies very much in appearance. Much of it distinctly retains its woody structure, pieces being found occasionally so little decomposed that they can be used for the same purposes as recent wood. In some cases, again, the process of decay has gone so far that all traces of ligneous fibre are lost, and many such varieties in lustre, colour, and general appearance can scarcely be distinguished from true coal. Other kinds are earthy and loosely coherent, varying in colour from

black to reddish yellow; while in certain localities it is met with of a peaty character. When brown coal is newly mined, it is generally in a much damper state than coal of carboniferous age. It contains less carbon (the amount of this element varying from 50 to 70 per cent.), and more oxygen in proportion to the hydrogen than common coal; the hydrogen and nitrogen being in nearly the same proportion in both kinds. Owing to its composition, therefore, much water is formed in burning it, a property which diminishes its value as a fuel; still it is of great service where better kinds cannot be obtained at a moderate price. From some of its varieties paraffin oil and other products are now largely distilled in Germany, these products having a much closer resemblance to those obtained from wood than to those from ordinary coal.

In the British Islands coal fields stretch over an area equal to about $\frac{1}{22}$ of their whole extent, and have hitherto produced an enormously larger quantity of coal than those of any other country on the face of the globe, although the workable deposits of the United States are of much greater extent. Our most northerly mining district is the little coal field of Brora, in Sutherlandshire, where a pit was first opened nearly three centuries ago. It happens to be of oolitic age, and although it has not been continuously worked, a large quantity of fuel has at various times been obtained from it. The great coal-bearing strata of Scotland, however, are of true carboniferous age, and stretch across the midland valley of the country from the shores of Fife and Haddington on the east to the

coast of Ayrshire on the west; and within this belt of some 30 miles in width nearly all the productive coal seams are situated. But there is a not inconsiderable field, lying for the most part in Scotland, adjoining the Solway; and a small one on the English side of the border, near Berwick-on-Tweed.

Passing now to the chief English coal fields, which are much more extensive than those of Scotland, we find them dotted here and there over the country; sometimes almost contiguous; sometimes in widely separated districts; but lying almost wholly to the north and west of a line drawn from Bath to Hull. The first that we meet is the great and early famous one of Northumberland and Durham, while some 60 miles south of it lies the still larger Midland coal field, situated in the southern part of Yorkshire and adjoining counties. Not far to the west is that of Lancashire and Cheshire, ranking fourth in size, or at least in richness. At a comparatively small distance to the south-west of this one, if it be not actually continuous with it, is that of North Wales. Continuing southwards, we have the North Staffordshire area, both it and the previous one being large coal fields. Of about equal size is that of South Staffordshire and Shropshire. In a detached, compact basin, containing about one-third of all the still available coal in Great Britain, are situated the rich seams of South Wales; and across the Channel, at the mouth of the Severn, we reach the most southern English coal field, unless, indeed, the hope is ever realized of finding seams of coal under the chalk in Kent. Besides these there are a number of

smaller coal fields, which I need scarcely particularize here.

Although rocks of carboniferous age extend over the greater part of Ireland, and probably at one time in the earth's history there was also a great development of coal-bearing strata, yet what now remain of these are of very limited area; so much so, that according to the most recent estimate, the total quantity of unworked coal in the country scarcely exceeds what is now raised in Great Britain in a single year. The largest coal field is in Leinster, and consists chiefly of anthracite; but bituminous coal occurs in Tyrone, Antrim, and other counties.

In their Report, published in 1871, the Royal Commissioners give, as the result of their inquiries, an estimate of the actual quantities of available coal in known British fields, at depths not exceeding 4000 feet, and in seams not less than one foot thick, of which the following is a summary:

	Tons.
South Wales	32,456,208,913
Midland (Yorkshire, Derbyshire, and Nottinghamshire)	18,172,071,433
Northumberland and Durham	10,036,660,236
Lancashire and Cheshire	5,546,000,000
Bristol	4,218,970,762
North Staffordshire	3,825,488,105
South Staffordshire, Coalbrookdale, and Forest of Wyre	1,906,119,768
North Wales	2,005,000,000
Smaller English coal fields	2,041,620,251
Total of Scottish coal fields	9,843,465,930
Total of Irish coal fields	155,680,000
Grand total	90,207,285,398

But by taking into account the coal which probably exists under the Permian, New Red Sandstone, and other superincumbent strata in the United Kingdom, the Commissioners increase their estimate of the quantity still available for use to 146,480 millions of tons.

On the Continent there are a number of more or less extensive coal fields, but, so far as is yet known, in no sense are the possessions of any other division of Europe at all equal in value and importance to those of Great Britain. France possesses one in the north, lying in the departments of Nord and Pas-de-Calais, whose position is peculiar, from being covered with a considerable thickness of chalk strata. Other coal-yielding areas are situated in the central departments of Loire and Saone-et-Loire; and there is yet another to the south, in the departments of Gard and Ardèche. The entire yield of the French coal fields, however, though considerable (17,000,000 tons annually), is still far short of meeting the wants of the country, so that a further supply of 7,000,000 tons is imported from Belgium, Prussia, and England. For her size, the little kingdom of Belgium has a greater store of coal than any other country of continental Europe. The field has not a very great area, but contains a large number of much contorted seams; these are actively worked, and some are reached by the deepest pits in the world. Its actual extent is about 100 miles long by an average of 5 in breadth, and stretches between Mons and Liege. The portion lying in the province of Hainaut is the most productive, the total yield of

the country being about 20,000,000 tons, of which a considerable quantity is exported. Important coal regions occur here and there through North Germany. In Westphalia, Rhenish Prussia, Rhenish Bavaria, and Silesia, considerable quantities of coal are raised from the beds of the coal measures proper; and of these districts, that of Westphalia, where the coal extends over an area of 1000 square miles, is the most extensive. But in Prussian Saxony, and through a great extent of country between the Elbe and the Vistula, deposits of the brown coal of the Tertiary formations also occur, which are now extensively worked and consumed for domestic and manufacturing purposes. In 1872, the German Empire had an output, estimated at 50,000,000 tons, including all kinds of coal. Austria, considering the wide extent of her territory, is not particularly well supplied with fossil fuel; but the working of such beds as are known, and the search for others, has been pursued with more than usual energy of late years, owing to the growing scarcity of wood, and the increased demand, arising from the prosperity of her manufactures. The older coal occurs chiefly in Bohemia and Upper Silesia, while in the former province also, as well as in Hungary and the Austrian Alps, there are considerable stores of brown coal, some of the beds being of remarkable thickness. So recently as 1853 a valuable field of lias coal was discovered in Southern Hungary. The total annual yield of the Austrian Empire in 1871 was 8,575,000 tons. Spain includes some valuable coal seams among her rich deposits of highly-prized minerals; but, owing to the unsettled state of

the country, they have not been much opened up. They are situated in Asturias, Cordova, and Catalonia. Italy contains some beds of anthracite in the north of Piedmont, and some coal, resembling that of the carboniferous age, in Sardinia ; but the production on the whole is trifling, and the only considerable supply of fossil fuel is obtained from the lignites of the tertiary rocks, which in several Italian districts occur in deposits of great thickness and of good quality. Lignite, indeed, is the only mineral fuel of much importance in the Mediterranean countries generally. The abundance of wood in Scandinavia has perhaps hitherto rendered the inhabitants of that northern region comparatively indifferent about the search for mineral fuel; but according to recent accounts, some valuable coal fields have been discovered in the Swedish province of Skara, and a number of thin seams of coal have also been proved in the island of Ardöe, in Norway. A coal mine in the Jurassic formation has long been worked at Höganas, in the south of Sweden. European Russia is another country from which very little has been heard respecting the possession of coal fields till recent years; yet in that portion of the vast territory governed by the Czar, there appears to be an extensive development of carboniferous strata containing numerous, though comparatively thin, seams of coal. As yet the Polish field is the most extensively worked, but there is a large central basin, 600 versts long by 400 wide, nearly in the centre of which stands Moscow. The same rocks extend about 1000 miles along both flanks of the Ural mountains; though, so far as is

yet known, they only contain coal seams in limited and interrupted areas. Perhaps the most promising coal field is the one stretching from the south-west of the Donetz River along the Sea of Azof for 180 miles. It is said to occupy an area of 20,000 square miles, and to contain more than a hundred seams of coal. A peculiarity of many of the Russian coal-bearing strata is that they do not belong to the upper or true coal measures which yield the great bulk of English coal, but to either the carboniferous limestone, or to the lower coal measures which contain workable coal seams in Scotland and in Northumberland. It is just possible that when the coal fields of Western Europe begin to fail in their supply, these distant Russian areas may do something to fill up the gap.

The comparatively primitive methods of mining, which prevail in Asiatic countries, have so checked the development of their mineral resources, that it is not easy to estimate the extent of the coal fields which some are known to contain. British India, in which we naturally take the greatest interest, appears to possess only a moderate supply of coal, which is not by any means of first-rate quality. With many barren intervals, coal-bearing strata extend westward from near Calcutta for a few hundred miles. Hitherto, the only field which has been much worked is that of Ranigunje, near the eastern limit of this region, occupying an area of 500 square miles, and containing workable coal to an aggregate thickness of about 120 feet. The whole quantity raised in India has not yet exceeded 500,000 tons per annum; but

efforts are now being made by the Indian Government to work the Ranigunje field more actively, as well as that of Chanda, in the central provinces. Coal of a superior quality is found in Assam, and deposits of lignite occur here and there in the Himalayan mountains. It would seem that there is an enormous development of the coal formation in the northern provinces of China, but accounts concerning the productive areas differ widely as to their extent. M. Louis Strauss, one of the Belgian consuls in China, has recently published a statement which gives the total area of these coal fields as 87,000 square miles, and if that of the island of Formosa be included, as 97,000 square miles. Another writer, however, puts the total at no less than 400,000 square miles. Baron Richthofen says, that in the province of Shansi the beds are from 12 to 30 feet thick, and adds that so little is the coal worked in those districts, that in the very country where coal most abounds, so desperate is the need for fuel, that the climate has been ruined by the cutting down of all trees and brushwood, and even the roots of grasses are diligently dug up to supply firing for domestic purposes. Coal, said to be of excellent quality, is also found in Japan, and in some of the islands of the Indian Archipelago.

The Australian colonies, whose treasures of gold and copper, as well as wealth of animal produce, derived from the unexampled increase in the number of their sheep, have for years excited the astonishment of the world, are not wanting in coal beds important enough to influence their prosperity. The Sydney district of

New South Wales, where there is a considerable development of coal-bearing strata, is the best known. Here, in the neighbourhood of Newcastle, there are several seams ranging from 3 to 5 feet thick, and the same beds have been observed about 700 miles to the north of this town. The annual produce of New South Wales is now over 1,000,000 tons, some of which is exported to India, where it realizes a good price. Coal also occurs in Victoria, but to what extent is not yet known. Quite recently a discovery of four seams, from 17 inches to 4 feet thick, is said to have been made in county Mornington, the field being estimated by the manager of a large gold mining company to contain 25,000,000 tons of coal. Tasmania also contains true coal, and New Zealand is rich in lignites.

On the African coal deposits, which occur in Cape Colony, along the banks of the Zambesi, where Dr. Livingstone discovered it, and collected gold dust in the same field, as well as in other parts of the continent, it is unnecessary to dwell. So, too, with respect to South America, I need only say that coal seams are known to exist in different provinces of Brazil, and likewise in Chili and Peru.

So far as extent of area is concerned, and in great measure also as regards thickness of workable seams, the coal regions of the United States claim an undisputed superiority over those of any other country, for we must put aside the Chinese basins from the comparison, till they are much more fully explored. Perhaps it may even fairly be said that, compared with the extensive deposits of mineral fuel lying to the

south of the great lakes, those possessed by any other nation are insignificant. Some shrewd practical men have, however, pointed out that when the great coal fields of the Union are more opened up by mining operations, or even more minutely and accurately surveyed, much of the coal area, now set down as productive, may be found to be barren. Still, after large deductions are made for interruptions, inaccessibly deep beds, and other causes rendering the mining of much promising ground either futile or unprofitable, enough is known to satisfy us that vast deposits of workable coal are spread over a great extent of the southern half of North America. According to one of the most recent authentic statements respecting the distribution of fossil fuel in the United States, namely, that of Professor Hitchcock, communicated to the 'Geological Magazine' for March 1873, there are eight distinct areas of the coal measures in that country, and these are as follows: 1. *The New England Basin*, in Massachusetts and Rhode, covering an area of about 750 square miles, and containing, it is believed, eleven beds, with a maximum thickness of 23 feet. The coal is a kind of anthracite, useful in smelting furnaces. 2. *The Pennsylvanian Anthracite*, which includes five separate basins, amounting to 434 square miles in area. According to the depth of the basin, the number of distinct beds varies from two to twenty-five, and the maximum thickness is 207 feet, while the average is estimated at 70 feet. This is the most important coal district in the United States. 3. *The Appalachian Basin*, occupying a total area of 63,475

square miles, extending from Pennsylvania to Alabama, and all of bituminous coal. The areas in square miles of the sub-divisions of this basin are 12,200 in Pennsylvania, 550 in Maryland, 16,000 in West Virginia, including a little in Virginia, 10,000 in Ohio, 10,000 in Eastern Kentucky, 5100 in Tennessee, 170 in Georgia, and 9000 in Alabama. In Pennsylvania there is an average thickness of 40 feet of this bituminous coal, and in West Virginia eleven of the twenty-four seams reach an aggregate thickness of 51 feet. 4. *The Michigan Basin*, extending to 6700 square miles in area. 5. *The Illinois Basin*, embracing an area of 51,700 square miles, which, however, also includes areas in Indiana and Western Kentucky. 6. *The Missouri Basin*, which is the largest of them all, comprising more than 100,000 square miles. It extends from Iowa to Texas, and is reached by several navigable rivers. 7. *The Texas Basin*, separated from the last one only by cretaceous beds, under which the coal beds may continue. 8. Areas of unknown extent in the Rocky Mountain region. The seven best known areas thus extend to a grand total of about 230,000 square miles, all belonging to the carboniferous system. In addition to this, the United States contain important deposits of coal belonging to newer formations. Notwithstanding the vast extent of her coal fields, the total production of coal in this country was in 1874 only about one-third that of Great Britain, the actual quantity being 41,500,000 tons, about one-half of which was anthracite.

The coal of the British possessions in North America

is found in Newfoundland, New Brunswick, and Nova Scotia, none whatever occurring in Canada proper. Although there is a great development of carboniferous strata in the Cumberland coal field of Nova Scotia, the number of workable seams is few, and does not in the aggregate exceed 16 feet in thickness. More productive, though of much smaller extent, is the coal field of Pictou, which contains five or six beds, all of considerable, and two of remarkable, thickness, one of them being 37 feet thick. In the island of Cape Breton another small coal field lies round the town of Sydney, and is believed to extend for some distance under the sea. It also contains some valuable seams. As already stated, the richly bituminous mineral known as Albertite is found in New Brunswick, but the coal seams proper of the colony are unimportant.

In referring to the quantities of coal required for various purposes, I have incidentally shown how indispensable to the prosperity of our leading industries is an abundant supply; but in order to see more clearly what our fossil fuel does for us, it will be necessary to go a little into detail respecting the mechanical force as well as the chemical products which can be obtained from it. Let us suppose, then, although the quantity is slightly under what is actually used, that 27,000,000 tons are annually applied in raising the steam which gives motion to our steam engines, and try to estimate the amount of mechanical power thus provided. There is some difficulty in doing this accurately, since the amount of coal consumed per horse-power varies greatly with the kind of engine, whether it is con-

densing or non-condensing, for example, and also with the form of steam boiler employed, as well as the construction of its fireplace and flues. It varies, too, of course, with the quality of coal selected, some kinds, as already explained, being much better suited for this purpose than others. According to the evidence of several witnesses of great experience examined before the Coal Commissioners, it would appear that in non-condensing engines from 7 lb. to 9 lb., and in condensing engines from 4 lb. to 5 lb., of coal may be taken as the limits of what is ordinarily consumed per horse-power per hour. But with a Corliss engine and a steel boiler the amount is reduced to 3½ lb., as against 7 lb. to 9 lb. in the one kind of older engine, and 2½ lb., as against 4 lb. to 5 lb. in the other. Good railway locomotives, again, consume scarcely more than 3 lb. per horse-power per hour. Yet in the opinion of many experienced engineers, who have long considered the matter, not less than 7 lb. per horse-power per hour are burned in raising steam in Great Britain, taking all cases into account.

It follows, therefore, that if our 27,000,000 tons of coal are reduced to pounds, and divided by 56 as the number of pounds consumed per horse-power per day of eight hours, we have—taking 300 as the number of working days in the year—the yearly work of 3,600,000 horses, estimating a horse-power to be what is conventionally considered as such in making calculations of the efficiency of steam engines. This, however, is well understood to be nearly double what any horse of average strength could perform, so that out of

27,000,000 tons of coal we really get the yearly work of about 7,000,000 horses, or 49,000,000 strong men. And if we had everywhere engines and boilers of the most approved construction, which we even now can command, the latent power of this quantity of fuel would be equal to the annual work of nearly 17,000,000 horses, or 119,000,000 men; or, supposing no increase in the amount of steam power to be required, we should then be able to reduce the quantity of coal consumed for this purpose by nearly two-thirds. What future improvements in the steam engine may accomplish in the way of still further saving fuel, no one can predict; but that the look-out is hopeful enough may be gathered from the opinion of Sir William Armstrong, who states that in the best of our present engines, not more than one-tenth of the theoretic power of the coal is utilized.

In a Return to the House of Commons, dated 9th August 1871, containing certain statistical information respecting the manufacturing establishments of the United Kingdom, there are columns giving the relative amount of steam and water power employed. It embraces, however, neither the engine power required in the railway traffic nor in collieries and metalliferous mines, nor in steamships; there are also a number of minor industries excluded: still, the Return, showing as it does the extent of motive power necessary for most of the manufactories and workshops in the country, gives us a clear and interesting view of what our position would be without our coal fields. The American writer, R. W. Emerson, in his 'English

Traits,' says, "Its (England's) short rivers do not afford water power, but the land shakes under the thunder of the mills." We are not absolutely without water power, but for the purposes included in the above Return we can make it available for only $\frac{1}{13}$th part of the work, the amount performed by the aid of steam being equal to 922,000 horse-power, while that done by water is only equal to 72,000 horse-power. And if we take into account the steam power which drives our locomotives and propels our steamships, and also that which, in the great majority of cases, raises the minerals and pumps the water from our mines, the disproportion would be vastly greater.

So much for the dynamic force of coal when applied to generate steam. Let us now see what can be obtained from it when treated by chemical processes. When submitted to destructive distillation in retorts or other close vessels, it yields many curious and useful products; one of the best known being the coal gas, which lights up our streets and dwellings. Other bodies, both liquid and solid, of much commercial value, manufactured before the days of gas making from coal, are now procured from it as collateral products in the production of gas. In recent years, another highly interesting class of products has been prepared from coal by distilling it under conditions, calculated to prevent as much as possible the formation of incondensable gas. But before enumerating any of these, I shall take a brief glance at one or two of the earlier attempts to utilize the volatile products of coal, long ere the achievements of modern chemistry were avail-

able to guide the experimenter. So far back as 1694, a patent was secured by Martin Eele and others for "a way to extract and make great quantities of pitch, tarr, and oyle out of a sort of stone." One can hardly doubt that this "stone" must either have been coal or bituminous shale. At all events, we find the germ of the modern process of distilling coal described in a patent, dated 1742, by M. and T. Betton. By their method they obtained "an oyl extracted from a flinty rock for the cure of rheumatick and scorbutick, and other cases." "The black, pitchy, flinty roch, or rock which is commonly found lying next and immediately over the coal in coal mines," is first powdered, and "put into a furnace, covered down close with an head to it, and worked with fire, which will extract the said oil from it." Little, however, is known about the commercial success of manufacturing chemical products from coal till works were established at Muirkirk, in Ayrshire, by the Earl of Dundonald, to produce them by a process which he patented in 1781, and which was afterwards extended by Act of Parliament for twenty years. By this process a tar, yielding brown oil, naphtha, and ammonia, was obtained by condensing the vapours arising from heating the coal in a kind of kiln—coke resulting as a residue. It would appear that this coke was used for smelting iron; that the residual tar, after the oil and naphtha were extracted, was employed for coating ships' bottoms and other woodwork, as well as for making lampblack; and that the naphtha was sold for making varnishes, for burning in lamps, and for other purposes. These, or at least similar works, *were in operation* at Muirkirk for nearly fifty yaers,

and only ceased when the establishment of gasworks in large towns, through producing the same bodies as by-products, rendered such special tar ovens, as they were called, no longer profitable. Before passing from the Earl of Dundonald's process, I may refer to a curious incident in connection with it, and another famous patent already alluded to, of much later date, for obtaining paraffin oil from coal, but specially applicable to cannel coal. It shows how one may approach the threshold of a valuable discovery and yet entirely miss it. It so happened that one of the seams of coal, which was distilled under Lord Dundonald's patent, contained within its thickness a layer of cannel coal, which, for want of knowing better, the workmen at that time threw away as useless. If, instead of rejecting it, they had put this substance into the kilns, it is not unlikely that one of the most valuable discoveries in practical chemistry during the present generation would have been anticipated by twenty or thirty years.

Returning now for a little to the manufacture of coal gas, and the utilizing of those secondary products obtained in the process which has also long constituted an important branch of manufacturing industry, I give in the first place two tables, showing the relative quantities of the products from the distillation of a ton of two kinds of coal.

NEWCASTLE CAKING COAL.

Products per Ton.

9500 cubic feet of gas.
1540 lb. of coke.
90 lb. of tar.
80 lb. of ammoniacal liquor.

LESMAHAGO CANNEL COAL.

Products per Ton.

10,100 cubic feet of gas.
1,390 lb. of coke.
120 lb. of tar.
64 lb. of ammoniacal liquor.

Since another volume treats on coal gas, I need scarcely refer to it further here, than to repeat what has been incidentally explained already, namely, that cannel coals as a rule yield it of a greater illuminating power, and generally in greater quantity, than ordinary bituminous coals of the best kind. But it is important to bear in mind, that gas for illuminating purposes can be prepared from other substances besides coal; for at different times oil, resin, peat, and wood have been employed to yield it. Bituminous shale also produces it in large quantity. We have seen that in gas making the consumption of coal is very great, and it is desirable, and now probable, that we shall soon be able to diminish the drain upon it for this purpose by employing a material less useful in many other ways, such as shale. As is well known, gas under certain circumstances can be more economically employed as a source of heat than a coal fire. In towns it is always at hand, and can be applied by the use of burners constructed for heating purposes at a moment's notice. This readiness of application is also taken advantage of in the gas engine, which is singularly convenient in circumstances where room is scarce, and where it would be too costly or troublesome to keep up a continuous supply of steam.

As indicated in the above tables, when coal is distilled in gas retorts, two kinds of liquids are formed from the condensable vapours which pass off along with the incondensable gas, namely, the tar or rather the tar mixture of which I have spoken, and ammoniacal liquor. The latter floats, by reason of its lightness, on the tar, and consists of a solution of various salts of ammonia, but chiefly the carbonate and sulphide. Crude gas liquor is now the principal source of ammonia. This alkali being easily volatilized by heat, its vapour only requires to be passed through sulphuric acid to convert it into sulphate of ammonia; or, by saturating the gas liquor with hydrochloric acid, sal-ammoniac or chloride of ammonium is formed; and from either of these compounds carbonate of ammonia or smelling salts can be readily made. Ammonia and its compounds are valuable substances in dyeing, for manure, in pharmacy, and for many other purposes.

The coal tar or gas tar is a thick black liquid, heavier than water, which accumulates at the bottom of what is called the tar well in gasworks under the ammoniacal water. Every ton of coal distilled generally yields from 10 to 12 gallons of this tar. It consists of a considerable number of distinct liquid and solid substances, most of which can only be separated by tedious processes. Only some of them are of commercial importance; but the number which can be usefully applied in the arts has increased considerably of late years. When coal tar is distilled in an iron still, it yields in the earlier stage of the process crude naphtha, and in the later, when the temperature

rises, a heavier fetid-smelling liquid called *dead oil.* There remains in the still a residue of the glossy black substance, pitch. The naphtha is purified by treatment with vitriol, which, from its greater specific gravity, rapidly sinks to the bottom, carrying certain tarry impurities with it. The upper layer of clear liquid is then mixed with quicklime to remove further impurities, after which the naphtha is distilled, and is then nearly as colourless as water. Formerly it was burned in specially-constructed lamps, and it is useful as a solvent of indiarubber, guttapercha, and other bodies: but at present the chief value of coal-tar naphtha is as a source of *benzole*, of which it is largely composed. Benzole is a solvent of wax, fat, and volatile oils. From it is prepared nitro-benzole, a body of some use in perfumery, as it possesses an odour resembling that of bitter almonds, but it is more interesting in reference to the preparation of some beautiful dyes.

Dead oil contains a considerable quantity of creasote, and is one of the best and cheapest substances for preserving wood in damp situations. Coal-tar creasote, or, as it is more generally called, carbolic acid, is separated from the dead oil by stirring it with soda, in which the creasote dissolves and sinks to the bottom as a separate layer. This is afterwards treated with sulphuric acid, which separates the carbolic acid. This body is now extensively used as a disinfectant. Carbazotic or picric acid, a beautiful yellow crystalline substance, is in turn prepared from carbolic acid by treatment with nitric acid, and forms one of our most

valuable yellow dyes. A superior lampblack is obtained from dead oil by simply burning it in suitable galleries, so as to yield a fine deposit of soot.

The pitch is used to produce an artificial fuel; in the preparation of an artificial asphalt for foot-pavements or floors, by mixing it with small stones; and in the manufacture of roofing felt, by incorporating it with a loose batt of tow and hair. Sometimes it is distilled in brick ovens to yield pitch coke, which is an excellent fuel for ironfounders, as it is quite free from sulphur and yields little or no ash. Coke oil is also obtained in the process, but is of little commercial importance.

Of all the chemical products from coal, however, what are called the aniline or coal-tar colours have attracted by far the greatest share of public attention; but as these and alizarine are described in another volume, I need not enter into it here.

It has been more than once pointed out that we get two different classes of products from coal, according to the temperature at which it is distilled. At least, if the two sets of bodies are not entirely different, they are so in a great measure. When it is distilled at a high temperature, the result is ordinary coal gas as the chief and most valuable product, and those other substances whose natures we have just been considering, such as ammonia, naphtha, benzole, creasote, and pitch, are obtained as secondary products from the gas tar. But when coal is distilled at a low temperature, that of a dull red heat, we get as a principal product vapour which condenses into an oil, some of the ordinary in-

condensable coal gas being, however, also produced. The crude oil thus obtained yields, on further treatment, liquids of different specific gravities, namely, a heavy oil, used for lubricating purposes; a lighter oil, of great service as a lamp oil; and a small quantity of a still lighter liquid called naphtha, distinct from, but in some points resembling, gas-tar naphtha. The two heaviest of these liquids are usually called paraffin oils, since they contain the solid substance paraffin, it being obtained from them by refrigeration and pressing in canvas bags. In this process some ammonia is procured, just as in the manufacture of gas.

It will greatly help us to understand the importance of this second and distinct series of coal products, if we travel back some years in point of time, so as to pick up a few of the chief dates in its curious history. In the year 1830, the German chemist Reichenbach discovered the beautiful crystalline substance paraffin in the tar of beech wood, and found that it also existed in small quantity in coal tar. He pointed out, too, that it would be a great desideratum if some process were discovered by which it could be profitably made on a large scale. It would appear that as far back as 1833, a Mr. Richard Butler, by a process of producing oil from bituminous shale, was in a fair way towards succeeding in this. At all events, it is almost certain he made an oil containing paraffin, for his "No. 2 quality" is stated to be "free from nephthaline," but when the heavier portion of it is exposed to a low temperature, there soon appear "small flakes of a white odourless and light substance, which is a com-

pound of carbon and hydrogen." From a similar substance a Frenchman, named Du Buisson, obtained oil and paraffin in 1845, and his method of distillation was tried on a manufacturing scale for several years. Both of these men patented their processes, as did also Mr. R. Reece, in 1849, another for obtaining paraffin from peat. Through using a comparatively poor raw material, neither of these practical chemists was able, however, to make his project a commercial success, and it was reserved for Mr. James Young, who carried on his researches in entire ignorance of these earlier schemes, to solve the problem by operating on a far richer substance, namely, the Boghead cannel coal, to which I have referred in a former page. Paraffin oil and paraffin were made on a most extensive scale from this coal by Mr. James Young and his partners at Bathgate for twelve or thirteen years previous to 1864, and perhaps it was the continually increasing demand for the products of this new industry that initiated, or at least greatly stimulated, its now powerful rival, the American petroleum trade. Although it is beyond question that the extremely successful process which Mr. Young patented in 1850 was entirely his own invention, it differed in no essential respect at least from Du Buisson's, except that it was applied to coal and not to shale. More remarkable, however, is the fact that coal has since almost ceased to be the raw material from which paraffin and paraffin oil are prepared, and that manufacturers are now by preference distilling these bodies from the richer bituminous shales of the coal measures, that is,

from a closely analogous substance to what has failed to give profitable results in earlier trials.

Now that I have considered coal with reference to its distribution, its nature as a mineral, as a source of light and heat, and, lastly, as a material from which by chemical processes various serviceable products can be obtained, we are in a position in some degree to understand why the various estimates which have been formed of late years respecting the duration of our coal fields vary so much, and how difficult it is to come to any satisfactory conclusion on this important question. The total available coal in the United Kingdom in 1870, at depths not exceeding 4000 feet, and in seams not under one foot in thickness, as we have already seen, was, according to the careful estimate of the coal commissioners, 146,480 millions of tons. Since then fully 500 millions of tons have been raised, so that not more than 146,000 millions remain. Taking our present annual production at 125 millions of tons, and supposing it not to increase, our coal supply would under these circumstances last 1168 years. There are not wanting persons, indeed, who take the extreme view that it may actually serve all the wants of the country during that time, thinking that hereafter the population will but slightly, if at all, increase. On the assumption, however, that the present rate of growth in the population and productive industry will continue, Professor Jevons a few years back estimated that 110 years would suffice to exhaust the whole of our coal. Mr. Price Williams, on the other hand, holding the view that the rate of increase in the con-

sumption of coal will for several reasons greatly diminish, subsequently estimated its duration at 360 years. This view is probably the one most largely shared in, so far as known circumstances can enable anyone to solve such a problem.

Apart, however, from the relation in which this question stands to the probable increase in the population and manufacturing power of the country, there are other things to consider which may in no small degree change the aspect of matters. The recent high price of coal set agoing several companies for the manufacture of condensed peat, and drove some of the gas companies in Scotland to substitute shale for coal to yield gas; so that here are two ways in which the fact of coal becoming dear may check the drain upon it. Some disturbance of the existing arrangements in gasworks being necessary when shale is used, the companies have for the present returned to the employment of coal; but so suitable are many extensive beds of bituminous shale found in the coal measures for making gas, some of them yielding 7000 cubic feet per ton, that any considerable permanent increase in the cost of coal would probably result in saving nearly the whole of what is now consumed in this manufacture. Even now the oil which has been of late years so largely manufactured from this shale, as well as the somewhat similar body petroleum, of which such astonishing quantities are found in the United States, furnish a cheaper and equally good, if less convenient light than coal gas. Paraffin oil and petroleum can also of course be used as a source of heat, and there is

a likelihood that were some well-contrived furnace constructed for burning them, their employment for this purpose would become extensive. As yet, only the richer shales have been used for the production of oil, and those who are best acquainted with the subject are sanguine, that by some simpler apparatus than what is at present in use, shales now looked upon as worthless will before long be profitably distilled. It is but a very few years yet, since the richest of these were considered to be of any value in this country, and it is now certain that many of our beds of shale may be reckoned upon as a material addition to our stores of fuel, although to what extent can only be roughly guessed. We know, however, already that those seams of this substance which may be roundly taken at from one-third to one-half the value of coal, contain many millions of tons.

How far peat will take the place of coal when the cost of the latter is much enhanced, is a contingency which has perhaps a still more important bearing on the question of the duration of our stores of mineral fuel. That it will do so to no inconsiderable extent we may be quite certain. During the past thirty years many well-directed efforts have been made towards utilizing the material in the very extensive peat bogs which exist in Ireland, but beyond producing, by compression or other treatment, a compact and useful fuel for domestic use within areas extending to no great distance from the bogs, little else has as yet been accomplished. Sir Robert Kane, who has long devoted great attention to this subject, writing

in 1864, says that "the extension of the railway system in Ireland, as well as the low rates of freight for sea-borne coal, have deprived the question regarding peat as a fuel of much of the importance formerly attached to it." This was of course written before the anxiety about the possible early exhaustion of our coal fields had been thoroughly aroused, and before the recent great advance in the price of coal had been anticipated, so that the question has now quite a different aspect. Thirty years ago the extent of peat bog in Ireland was estimated by Sir R. Kane at nearly three millions of acres, and a considerable portion of this averaged 20 feet in depth. This immense store of peat is probably not yet greatly diminished, and there is also a large area of it in England and Scotland. The conversion of the better qualities of much of this material into a fuel, which will be convenient and economical in many localities hitherto preferring to burn coal, is plainly only a question of time. It was truly said some years ago, with reference to the comprehensive schemes from time to time projected for utilizing Irish peat, that "the bogs are often very extensive and deep, and in the present condition of this country with regard to mineral fuel, are more likely to swallow up treasure than to yield it." Perhaps this may still be the probable fate of such enterprises. Even when best prepared, peat never possesses more than two-thirds, and more generally it has only one-half, the heating power of coal. Besides, weight for weight, peat is a much bulkier substance. The advantages of using coal, so long

as its price is not excessive, are for these and other reasons not easily outweighed. Still the day must come, when our black diamonds will reach a value that will check the rate at which we can afford to burn them. There are signs that it is beginning to dawn upon us already, and peat in some form or other ought to lend considerable aid in preventing the approach of a time, when the great benefits we derive from our extensive deposits of coal will be materially lessened.

But of more importance than providing serviceable substitutes for coal are the various plans for preventing waste in its combustion. The iron manufacture is perhaps the field where the greatest results in this respect may be expected. In most of the English districts coke is the fuel consumed in the blast-furnaces, but in the Scotch, it is raw bituminous coal. In either case a great saving of fuel takes place, if the furnace is closed at the mouth with a valve, so as to utilize the combustible gases produced in the smelting process, which are still in many instances allowed to escape into the atmosphere. There is high authority for stating that with open-mouthed furnaces, four-fifths of the heating power of the fuel is wasted. The idea of saving these "waste gases," as they are called, is old, but the practice of actually doing it is comparatively new, and is far from universal even now. Yet so remarkable is the effect when this is attended to, that in the Cleveland district of Yorkshire alone, on the annual production of 1,000,000 tons of pig-iron, Mr. Lothian Bell estimates the saving at 600,000 tons

of coal. A difficulty attends the adoption of this plan, however, when the coal is employed in the raw or uncooked state; but quite recently, by a furnace designed by Mr. Ferrie, of the Monkland Iron Works, this difficulty is overcome, and a ton of iron can be smelted by this new furnace with 34 cwt. of coal, instead of the 54 cwt. required in the older ones. Mr. Siemen's regenerative furnace is also destined to be of essential service in some branches of the iron manufacture, as well as in other industries. With it 12 cwt. of coal suffice to melt a ton of steel, whereas 3 tons of coke are required to accomplish this in the ordinary Sheffield furnace. The Bessemer process for making steel, again, consumes far less fuel than the ôlder methods, and as the production of this peculiar kind of steel is rapidly extending, the saving of fuel by it will become considerable. Perhaps the making of coke is one of those processes where least success has attended the attempts to utilize waste heat, and still even here plans are in use for the purpose which are not entirely failures. It is unnecessary to refer again to the results of recent, and to what may be expected from future, improvements in the steam engine, with reference to the consumption of fuel. Nor need we wander into the details of kilns, furnaces, and other heating apparatus employed in such arts as glass making, distilling, sugar refining, alkali making, and many others, to point out how in all likelihood much less coal will one day be found to do the same work.

And having put off to the last the question of economy in fuel for domestic purposes, I need only

mention the fact that there, too, the waste is at least as great as in any other direction. Not to speak of those in use in Germany, from which a hint might be taken, the stoves of Sylvester and Dr. Arnott, besides many ingenious ones of more recent date, are adapted to secure for us a much greater quantity of heat from a given quantity of fuel, than the grates ordinarily in use in this country. But the length of time some of these have been before the public without coming into general use shows, on the one hand, how difficult it is to secure the introduction of any new contrivance of this kind, if it be attended with a little extra trouble; and on the other, how much the luxury of an open fire is preferred to the economy of any kind of closed stove. Still we shall come in time to think that some plan for burning coal in our homes to much greater advantage than we do at present is worth a little attention, and that even the cheerfulness of a fully exposed fire may cost too much. Further, when for every purpose the best schemes already put forth for burning coal economically are widely adopted, more will be coming to maturity, and the march of science, which is continually putting to-morrow in advance of to-day, will in due time bring others still better to the front. Any conceivable estimate of the duration of our coal fields made half a century ago would assuredly be far wide of the mark now, and the best that can be conjectured now is not likely to seem more truly prophetic, after another fifty years have rolled away.

WORKING OF COLLIERIES.

By Warington W. Smyth, M.A., F.R.S.

Eight years ago the total quantity of coal raised in Great Britain in twelve months had attained what our fathers would have called the fabulous amount of a hundred millions of tons. For some time before, the statistics of the subject seemed to show that from two to three millions of tons increase over the previous year were annually produced; and so, in fact, it went on, till in 1873 the output exceeded 128,000,000 tons. But alas! for the theoretical views based on this annual increment, the effects of Lord Aberdare's "Act," co-operating with other causes, strikes, and inflated prices, have produced the natural result of a grand check; and the account for 1874 shows, instead of an increase, an actual decrease of two millions of tons.

Were a Methuselah among the miners to narrate his experiences as to the changes which from small beginnings have landed us amid these large figures, he would furnish a history of much general interest throughout, and of gradual improvement, but one in which the most striking part would belong to a limited portion of the present century.

"'Tis sixty years since" that an event took place which in some of the most productive districts greatly changed the character of coal-mining operations. Dr.

Clanny, George Stephenson, and Sir Humphry Davy, all about the same time, were at work upon the invention of a lamp which should be carried securely through spaces filled with inflammable air. Clanny has the credit of being the first, in 1815, to devise a lamp which was actually tested in an explosive atmosphere. But Davy's researches on flame and his suggestion of the wire gauze, introduced in 1816, so entirely took the lead, that a new era of coal mining may be said to have begun, when Buddle, the first coal viewer of his day, hanging up the lamp in a fiery place, and watching it grow red hot without firing the gas, cried exultingly to his companions, "We have at last subdued this monster." *

The introduction of the safety lamp made it possible further to systematize and to enlarge the scale of working of valuable coal areas. It not only facilitated the full examination of the excavations of a mine, and the adoption of due precautions against the firedamp, which could thus be securely approached; but it rescued from neglect and waste many a tract which, without such a protection to the men entering it, would have appeared too dangerous to trench upon.

But strange as it may seem to be, of the sixty years which have sped away since Davy's visit to the North, a third part passed without any very great change, either in the inner or outer appearance of coal mines, developing itself. Then came the rapid extension of steam navigation, and the startling progress of the

* Evidence before Select Committee, House of Commons, 1835, p. 154.

rail; and the last forty years, introducing into the coal trade the conditions of urgent demand and frequent opportunity, have witnessed the remodelling of all the accessories of colliery work, except the first simple process of hewing the coal.

If one had any doubt as to this period of comparative stagnation, it would be set at rest by the distinct testimony of George Stephenson. Before a Committee of the House of Commons in 1835, that clear-headed engineer, after his vivid description as an eye-witness of the explosion at Killingworth in 1806, stated that he thought there had been no improvement for the last ten or twenty years, and that if a new colliery were opened out now, the same plan would be resorted to that was followed twenty years ago.

The Committee above mentioned was appointed in consequence of the terrible accident at the old Wallsend Colliery, which destroyed 102 lives; and the admirable evidence which was brought forward on the occasion gives a most convenient standpoint for the appreciation of the changes which have occurred.

Lighting of Coal Mines.

And, first of all, as to a secure means of lighting the mines. We have to remember that very many of our collieries, and even whole districts, are free from firedamp; so that nothing more than candles or open lamps are there needed. When, however, the seams are "fiery," and give off carburetted hydrogen, either from the whole mass of the coal, or in the more dangerous concentration of "blowers" or sudden outbursts,

the worse cases will require that safety lamps be employed throughout the entire mine, whilst in a large proportion of them, and especially where the exudation of gas is regular, the most approved plan is to limit the safety lamps to certain districts, and to use candles elsewhere. This mixed system, however, to be in any wise secure, must co-exist with a strict discipline, and with a suitable treatment of the ventilating air-currents.

In sixty years the Davy lamp has met with its full share of abuse and adverse criticism, and its friends have sometimes been injudicious in concealing or palliating its defects. Its small modicum of light is of course a palpable point of weakness, and this doubtless leads to danger, by tempting the men to remove the top or obstructive wire gauze when they think the air good, and particularly wish to see better in order to pick their coal clean. Scores of inventions have been brought forward—locks, and stamped pins of soft metal, self-acting extinguishers, and detectors, to prevent such tampering; and a lock of one sort or another is now almost invariably used, and guarded by special rules. A very ingenious method is that exhibited at the Paris Exhibition of 1867, by M. Arnould, of Mons, and since modified and patented by Craig and Bidder in this country—of locking by a spring, and unlocking the lamp on the poles of a powerful magnet, so that, except at that particular point in the lamp cabin, in the hands of the presiding official, the gauze cannot be unscrewed. No objector could point out more distinctly than did Davy himself, that the safety of the lamp ceased, if its

surface were exposed to a current of inflammable air moving at a greater velocity than 5 feet or 6 feet a second. The warning was unfortunately overlooked for many years, and the danger is still apt to be ignored, although ready to be brought into play by an unusual draught or even puff in a foul stall, or in the gas-drift, such as would follow on a man's walking against the wind, or where an obstruction increases the velocity of the air, or if a person advancing at a medium pace should stumble, or otherwise jerk his lamp. And many cavillers stepped out of scientific circles and termed it a failure, asserted that it was "practically unsafe," and predicted that it must be replaced by this or that improved form.* Yet after so many years of fiery ordeal, after thousands of them being in daily use and exposed to the many unfavourable conditions of mining life, there remains the experience that scarcely half a dozen cases of accident can be traced to the Davy, and the significant fact that to this day it is more generally approved and employed than any other form of safety lamp.

This question, however, of liability to explosion in a sharp current of firedamp or foul return air has of late years been thoroughly sifted by a Committee of the Northern Institute of Engineers, and their main results showed that a current of 8 feet per second would pass the flame from the Davy or the Mueseler (Belgian) lamp; that 9 feet and 10 feet per second

* Mr. John Taylor, of London, "agreed with Mr. G. Gurney, as to the inefficacy of the Davy lamp." Select Committee on Accidents in Mines, 1835, p. 19.

would pass it through the Clanny and Stephenson lamp respectively; and 12 feet through the Davy, provided with a shield from top to bottom.

Alarmed by these statements, a number of viewers and lamp makers have worked hard at new modifications; and as far as resistance to velocity goes, some of the new varieties, among which may be mentioned Hann's and Bainbridge's, have successfully withstood currents of 40 feet and even 50 feet per second. But into these new constructions there enters another source of insecurity, viz. glass; and where the inlet and outlet of the air have to be so jealously guarded, there is a risk of creating such obstruction by successive plates of wire gauze, that the lamp will fail in its prime duty—that of burning.

Very generally, from its lightness for carrying, and its sensitiveness to a very small proportion of firedamp in the air, the Davy is preferred for the preliminary examination of the workings, before the men are admitted to their several places. In some instances the Clanny lamp, as giving a good light, is used by the officials and for surveys; and in some of the largest pits in the North it is extensively used also by the men. In many more mines, and especially in the North and in the Barnsley district, preference has been given to the "Geordie," or Stephenson lamp; and well shielded as it is against an ordinary current, and prone to be quickly extinguished in firedamp, it doubtless offers a high degree of security. In the Wigan district, years ago, the Mueseler lamp, long the most approved safety lamp of Belgium, with its excellent

light, was successfully tried, and I have since met with it in extensive use at several other English localities. Mr. C. Tylden Wright states that he has had 580 of them in daily use for fifteen years at Shire Oaks Colliery, that their average life is three years, and that since they were adopted no explosion has occurred, though it is admitted that the pit is very free of gas. At Wynnstay Colliery, North Wales, 600 Mueseler lamps are in daily employment, and about 25 glasses are broken per week. At Hafod-y-bwch Colliery, near Wrexham, 600 are also used, and the breakage is about the same, giving 1 in 24 broken per week. This is a large amount, and might appear to support the strong feeling against the introduction of glass into safety lamps which is still held by many experienced coal viewers; but it is not in the dangerous and critical part of the operations that these breakages mostly occur, and many of them seem to take place when the lamps are being carried to the cabin or up the pit to be re-lighted.*

There are thus, besides the simple Davy, some half-dozen patterns of safety lamps, which, having been admitted in numbers to the crucial test of practice, have shown that under ordinary conditions in mines they may be employed with confidence. Yet there are still questions, especially such as touch on the passing of the flame through the gauze by a blower, or current of air, or the puff from a distant explosion of powder,

* Joseph Cook and Co., of Birmingham, and Teale, of Manchester, are notable as makers of these lamps, and purveyors of the glasses.

which demand special caution, and, in some instances, further experiment and consideration.

Nothing can be more triumphant for those who augured well from the first successes of the Davy lamp in 1816, than an examination of the causes of accidents by explosion since that time, and a comparison of the cases, few and far between, where the lamp has been held to be in fault, with the many and great calamities proved to be due to naked lights. Innumerable are the *rencontres* with danger daily known to the officials of a fiery mine, and securely passed through by aid of their admirable, if imperfect, instrument.

Sinking of Shafts.

With the increasing exhaustion of the shallower parts of the coal fields, the sinking of shafts has become more than ever a matter of importance. The old workings by levels, adits, or soughs, and by inclines or slopes, passing in from the outcrop of the seams, are getting altogether eclipsed, even in hilly districts, by deeper workings, made accessible by pits. The greatly increased output also of the last forty years, and the modern requirement that every mine shall have at least two outlets, has constantly promoted the sinking of new shafts. Shortly before 1830 it was a matter of wonder, when a single famous pit nearly approached 300 fathoms in depth; now, we have Dukinfield, with a depth of 350 fathoms, and Rose Bridge with upwards of 400 fathoms. And, whilst the majority of the pits of collieries used, in the days of the elder Stephenson, to be 7 feet or 9 feet, or rarely perhaps 12 feet in diameter, it is no

uncommon thing, within the last few years, when making arrangements for a large area, to sink the shafts 14 feet, 16 feet, or even as much as 20 feet in the clear.

The statistics about the sinking of deep and difficult shafts are often a delicate subject for inquiry. Some have been entire failures, others have cost far more than was estimated; but it may probably be assumed that, except at a time of unusually high wages, most of these great undertakings have, within the last few years, cost somewhat less than similar works a generation before, and chiefly for the reason that the conditions are better understood. On the Continent, in the meanwhile, a number of ingenious methods have been devised, especially in France, Westphalia, and Belgium, for piercing down through the difficulties occasioned by overlying watery strata. The mode adopted by Messrs. Kind and Chaudron, of boring from the surface, *à niveau plein*, or without taking out any of the water, and then completing their lining or tubbing before proceeding to pump it out, is one which has now been effected in above a score of difficult cases with unvarying success, and at an extremely moderate expense.

Many new enterprises, to be attended by sinkings, naturally arose out of the anomalous and mischievous inflation of prices of coal and iron two years ago. In certain districts it was last year calculated, that preparations were thus making for increasing the output by one-fourth or even one-third; and this appeared to be the most natural way of making supply tally with demand, and of restoring that moderation in price which

had in this country been our special advantage, as compared with other nations. At that time the colliers and colliery speculations rode on the crest of the wave, though now they are in the trough of the sea, and many promising undertakings are checked, or even suspended. But amongst those which continue to advance are a few in which novel methods are being attempted, such as preparing blast holes with mechanical drills, and sinking by aid of a number of vertical holes put down by the diamond borer. Neither appears as yet to be regarded as a notable success.

Tubbing of Pits.

The engineers, or more properly coal *viewers*, of the beginning of the present century deserve much credit for the completeness with which they accomplished the exclusion of water from shafts by means of a lining, or "tubbing," fixed so as to face the watery strata. After planking, solid wood, and cast iron rings, resting on flanges, had been successfully tried, the system of employing segments of cast iron, flush towards the inner part of the shaft, and wedged back against the ground, is the form which has now been very largely adopted. And it is wonderful to see the success in the case of workings which are entirely dry, carried on beneath strata which, at the time of the sinking of the pits, poured in their hundreds or even thousands of gallons of water per minute. A source of trouble and expense in repairs has been the destruction of the cast iron by the fumes in upcast shafts, and by acidiferous waters; but to meet this, a further lining of the iron,

by close-jointed wood or by brick has been used with advantage. One of the most remarkable instances has been at the Shire Oaks Colliery, where no less than 180 yards of continuous cast-iron tubbing were put in, and where, after standing for many years, a length of 30 yards was, four years ago, changed in the upcast shaft, from the plates having been broken by the alternate contraction and expansion caused by changes of temperature, though, by aid of good protection, the substance itself was not in the least worn or corroded.*

Working of the Coal.

When we pass from these preliminary operations to the thousand and one forms assumed by the underground workings, we step into a field where the varying conditions of the seam itself and its roof and floor tax in a high degree the judgment and experience of a mine manager. The methods follow a variety of modifications between two extremes, viz. the *post and stall* system, or *bord and pillar*, in which a given district is at first worked over narrow excavations, so that no considerable fall from above shall take place, and the *long-wall* system, in which the whole of the available mineral is removed in successive slices, and the roof or superincumbent mass allowed to fall in. The most notable seat of the former is in our northern counties, and in the *stoup and room* of Scotland. The latter, "long work," has been chiefly practised among the thinner seams of central England, the very low ones of Somersetshire (down to 13 inches), and in the Forest of

* C. Tylden Wright, MS. communication, 1875.

Dean, and parts of South Wales. Yorkshire, particularly in the Barnsley seam, and portions of North and of South Wales, exhibit a number of other plans, more or less intermediate, which mostly require a study on the spot before an opinion can be formed on the reasonableness of their introduction.

At the first view it would appear that the long wall, clear and simple, admitting, too, of a most direct and powerful ventilation always bearing on the working faces, leaving no open spaces for the accumulation of gas, and clearing out everything as it advances, ought to bear the palm. And indeed, although generally used where the seams are low and the roof moderately good, it has been shown by some of its advocates to be capable of application more or less modified, even where roofs break very short, and where the seams are as thick as 14 feet, as at Church Gresley, or as the half height of the 10-yard seam near Dudley. There is no doubt that, in the face of difficulties and prejudice, the system has in the last few years made much way. It has been made to replace, in some instances, other modes which appeared to be fraught with more danger from explosion, and in many more has been preferred from motives of economy, and especially from the larger proportion of round or large coal which it commonly seems to give. Even on the Tyne and Wear, the classical stronghold of the bord and pillar, a number of very important workings are now conducted on a modified plan of the long wall. In few of these cases, can we expect to see the fine regularity of the pits in districts where all the circumstances are in

its favour, as in South Derbyshire or Nottinghamshire, and where a straight face of coal may be seen for hundreds of yards in length; but by leaving rectangular pillars of extra proportions, and working them off in long wall fashion, or by communicating different groups of excavations and avoiding the intermediate narrow work, many of the solid advantages of the long-wall method have been gained.

The system of working by bord and pillar has, in the course of this century, been submitted to a series of successive changes in the proportion of the parts; and for the following two reasons: 1st, that the pits have been gradually advancing from small depths, at the outcrop, on the western side of the field, to nearly 300 fathoms, or 1800 feet deep on the east; 2nd, that the pillars have come gradually to be considered not merely a temporary prop, to keep up the roof, but a source of merchantable coal at a future day. In modern arrangements therefore, instead of the old plans of leaving one or two yards thick of coal, which would rapidly crush down into powder, or even four or eight yards thick, which were apt to suffer from thrust and creep, or, in more favourable conditions, would not, after long-continued pressure, yield a saleable coal, quite different views are taken of the ratio between the openings and the supports in the first working. Thus, at Whitehaven, where the coal is very strong, the pillars are turned of 20 yards square; in the deep pits in Durham, dimensions of 24 yards by 30 yards are frequent; at Ryhope and at Seaham, where the depth is very great and where the workings are extended

under the sea, they have been made 40 yards by 40 yards; and at Monkwearmouth, for the purpose of ultimately getting the pillars by long wall, they have been extended to 60 yards in length. There is thus generally introduced a plan of extracting at first only about one-third of the coal, for the purpose of ultimately obtaining, with the greatest amount of security to life and property, the fullest proportion of available coal, by a regularly conducted operation of pillar working.

But the arrangements may also differ in another point. There are coal districts where, when the area of a colliery is but small, and where the capital of the proprietors is abundant, it may be found advisable to work by *back-stroke* only. The roadways are in such case driven out to the boundary, and the coal worked on a large scale back towards the shafts, leaving the *goaf* or exhausted space always behind and done with. On the other hand, the necessity for making returns, and especially in the case of extensive "royalties" or leased areas, renders it preferable, and indeed unavoidable, in most collieries to work *outwards* from the pits, or even to open out in several parts of the field at once, and thus to complicate the plan of the workings, and to introduce the objectionable feature of wastes or goaves variously intermingled with workings in the whole coal.

It is to Mr. Buddle and his contemporaries that we owe the very important modification (not always yet sufficiently appreciated) of not running the preliminary workings over a large area as a single monotonous plan, but of rather subdividing it into a series of

districts or "pannels," divided from one another by substantial ribs of unbroken coal. In this way, the space over which an accident would extend will be limited. If a creep, due to pressure and heaving floor, occur in one pannel, there will be a fair prospect of its being brought to rest when it arrives at the thick limiting masses of coal. If a fire broke out, it would be possible, by putting dams into the few orifices through the barrier, to isolate and probably extinguish it, without injury to the rest of the works. And even in the event of an explosion, if the air currents be properly managed, so that each pannel represents as it were a separate mine, there is fair probability of limiting its fatal effects.

Coincident with this division of the area into separate districts came the conclusion, that it is advisable not to allow the pillars to stand for too long a time unwrought, but that after a certain area of "whole coal" has been converted into "broken," by the driving of bords and the headways which intersect them, a commencement should be made with (as circumstances may demand) the thinning or splitting, or entire working off, of the pillars.

In the ultimate winding up of affairs, when retiring towards the shafts, it is expected that these barriers themselves, and the ribs protecting the main roads, nay even a great portion of the shaft pillars as well, may be gotten, and thus a percentage of the mineral obtained which, under favourable circumstances, would vie with that given by the long-wall system.

Among the intermediate methods of getting the bulk

of the coal, still largely practised in various parts of the country, may be mentioned particularly the *bank* work of South Yorkshire, the *wide wickets* of North Wales, and the *double stalls* often used in South Wales. These are separate and parallel lines of working, so wide (from 8 yards to above 30 yards) that the roof must come down in the middle, and ways for the men and the air have to be kept open along the sides by timber and pack walls formed of the fallen roof-stone. Between the several faces of working, it is often the case that advanced drifts (*bord-gates*, in Yorkshire) are pushed forward, for some yards at least, serving for exploration, and to some extent for drainage of the gas. The drawback of these systems is the multiplications of the goaves or gobs, so apt as they are to become the magazines of noxious gases, and the close juxtaposition in which they are placed to the majority of the men whose work is to hew the coal.

It is impossible to quit this portion of my subject without glancing at the actual getting of the mineral, the operation which involves the largest part of the expenses of a colliery, and probably that which gives the largest amount of trouble and annoyance to the agents.

The double-headed pick, wielded by a strong arm and directed by a sure eye, is still the "queen of weapons" in a coal mine. By it the kirving or undercutting is carried out to a depth varying from a few inches to three or four feet; if the jointing of the seam be such as prevents its standing for this operation, the coal may be hewn down bodily or "pinched" down with bars.

Then, in narrow workings, it may require also to be cut or sheared vertically by a similar, though sometimes heavier, pick. After this comes the wedging down, or the substitute, so largely adopted at the present day, of blasting with powder; and to the objections raised against this latter plan, that it shakes the coal more, and that it is sadly conducive to accidents, there is always returned the answer that, without the effective agency thus obtained, it would be difficult for certain collieries to maintain their place in the general competition. Where, in the meanwhile, are those mechanical appliances which, for above twenty years, have been subjects of description, discussion, patent rights, and experiment? The answer must be that difficulties, for the most part unforeseen, interfere with their application, and that a very few out of a long list can be held to show a promise of being really practical instruments. I had the opportunity of watching, as long ago as 1863, the remarkable kirving done by Mr. Firth's pick machine, driven by compressed air, at Hetton, and I am informed that it is still in use there, whilst a modified form of it, with improved air compressor, has long been steadily working at West Ardsley, near Leeds, and holes successfully in the stone under the cannel. Some of the rotary cutters are also well spoken of from the scene of their experimental application; and indeed, where circumstances are favourable, such as moderate height of seam, good roof and even floor, several of the machines appear to come very near to the border line of attaining a practical success; but it may be doubted, without doing injustice to the

ingenuity of the inventors, whether either of them has yet crossed that much debated boundary.

If we now turn from the face of coal, where either once or twice a day, according to the custom of the district, a fresh fall of the material is brought down, and look to the manner of bringing it out to the daylight, we shall find a surprising change wrought within the memory of man. The distance which the coal has to be conveyed may vary from a few score yards to one or two miles, and whenever it is at all considerable, the difficulty of keeping underground roads in good condition renders the question of maintenance one of great importance in the economy and in the power of dealing with a large traffic.

Underground Conveyance.

It is unnecessary to go back to the time when sledges were used for dragging the coal from the face to the bottom of the shaft, a plan aided by the slippery nature of the floor or underclay, and still employed in the early part of the journey, where seams are low and auxiliary ways have to be travelled before coming to the main roads. The "putting" or "carting" of this preliminary stage, although mostly done by boys, is a very expensive item, but so also is the cutting of extra height for a main roadway, and one source of cost has to be balanced against the others, in determining the best form for the work. In the north, Shetland ponies have been largely employed to do the work of the putters, with small boys only to drive them—a plan

of course not applicable where, as in Somersetshire, seams of only 12 inches to 15 inches thick are worked.

In the subordinate roads a single *corve* or small waggon, commonly called a *tub*, is handled at once, but on reaching the main road or rolley way, a number of them would be brought together. The *corve* or basket, in which throughout our most important districts all the coal was conveyed, up to some thirty years ago, is now almost a thing of the past, and the picturesque group —near the pit bank—of men occupied in the mending or weaving of the corves is almost everywhere replaced by the carpenter's or smith's work of preparing wooden or sheet-iron tubs, trams, or carts. A great point gained is where the height of the seam is sufficient to allow the same waggon which is to perform the journey to and up the shaft, to be brought into the stall or close to the face of the coal, and there to be loaded once for all. A small train of these tubs, with wheels of from 8 to 12 inches diameter, will then be drawn by one horse along the main road, instead of introducing the old intermediate carriage or rolley. Practice differs a good deal both as to construction and capacity of these tubs: in the north they contain from 6 to 12 cwt. of coal; in the south, especially in Wales, larger trams are often preferred, carrying a ton or more. The serious expense connected with the keeping, in the larger collieries, of a hundred or two hundred horses, induced engineers, many years ago, to study the means of substituting engine for animal power, to be applied to the traction along the principal roads; and in this great improvement the initiative has been taken by the

colliery districts of the north and of Lancashire, but the example has been followed up with remarkable rapidity by a great proportion of our larger British works.

In order to apply the power, either wire ropes are led down the pit from machinery at surface, or steam engines, generally with double-coupled horizontal cylinders, are placed for the purpose in a securely arched chamber underground. These are supplied with steam, sometimes from boilers at surface, in other cases from boilers adjoining the engines, whilst certain managers, and with great success, have applied compressed air conveyed down the pits from air-compressing machines fixed at the surface.

It has to be remembered that the natural conditions of the stratification vary so much, that the arrangements for employing engine power have to be applied in very different ways. If the seam be comparatively horizontal, with inclinations of less than 1 in 28, the full tubs may be hauled by a wire rope from the far end of an "engine-plane" to the pit bottom, but the empties will require also to be hauled back again by a rope, for which purpose a lighter one, the "tail-rope," is employed, working round a large sheave at the extremity. This being attached at one end to the full train, and at the other to the empties, pulls the latter into the interior of the mine, by the same movement of the engine which drags the loaded set to the pit bottom. Otherwise, in the case of a single line, the action is alternating. And if branch roads or planes pass off from the main line at intervals, they may, by

having ropes in them easily connected by shackle-joints to the principal ropes, have trains pulled along them in the same manner. This method, admitting as it does of the running of trains or "sets" of twenty to eighty tubs at once, and a speed sometimes as high as eight or nine miles an hour, has greatly lowered the expense of carriage, and, with other contrivances, increased the power of output. And thus, in extensive collieries, it is no uncommon thing to bring together to a central point, the pit or pits through which it is to be raised, as much as from 1000 tons to 1600 tons of coal per day.

The first way in which engine power seems to have been applied to traction underground, was in the simpler case of a seam dipping at the shaft bottom at an inclination of more than 1 in 28, and where the tubs can run down by gravitation and pull out the winding rope with them. Mr. George Stephenson relates in 1835, how about the year 1815 he was concerned with probably the first attempt of the kind, at the Killingworth Colliery, and how the number of horses kept was thereby reduced from one hundred to fifteen or sixteen.

In North Lancashire another method has come into use, that of an endless chain, revolving round wheels at both extremities of the road, at a speed of two to four miles an hour, the driving chain resting *on* the tubs, and these being hitched on at intervals of from 10 to 40 yards. Endless ropes too, of iron or of steel wire, and driven in the same manner, are now applied with much success. They are made to pass round

either a group of wheels or round a Fowler's clip-pulley, to keep them duly stretched. In one plan the tubs or cars are hitched on at intervals to the rope, in another they are attached in sets, and by this latter method, taking one out of several branches, 300 tons per day of eight hours are habitually drawn by a pair of 12-inch cylinders along an engine road of from 1000 yards to 1500 yards in length.

It is only during the period which I have selected for consideration, viz. since the invention of the Davy lamp, that these improved roads and means of conveyance have been possible. Edge-rails of wrought iron were introduced only about 1820, and in remote districts have not yet altogether supplanted the tram plates and narrow wheels which seem to have been almost universal, when George Stephenson and Nicholas Wood commenced those experiments on traction in and about the collieries which contributed so much to establishing railways, and thereby altering the whole condition of society.

The introduction of complicated machinery and high velocities underground has no doubt contributed a good deal to the risk of life and limb encountered by boys and men travelling to and from their work. But steps have been taken to meet the increased danger; refuge holes or recesses are cut or walled in the sides of the planes at 20 yards asunder, and distinct methods of signalling between the ends of a plane are enforced by the inspectors. Besides the more ordinary methods of wires and some kind of bell, electric signals are coming into play; and a safer method than any other

as regards the perils of travelling, is that of opening and maintaining a special road for the workpeople.

Winding in Pits.

In no department of coal working is the change effected during the last forty years so palpable and so striking as in the winding or hoisting through the pits. A man of but moderate age cannot fail to remember the appearance of the corves, one, two, or three in succession, swinging free at the end of the rope, in which the coal was brought to the surface; or, in other districts, may call to mind the great iron bucket, or "hudge," into which they were tipped at the bottom, to be again emptied out by capsizing at the top. And to those who have frequently visited the interior, the memory will be equally fresh of climbing awkwardly into the said bucket, and then taking the choice either to be lost in its capacious hold, or to stand on the edge and assist in booming off from the sides, or at that unpleasant point of meeting, where the speed was checked, to aid in avoiding collision when two ropes worked in the same compartment of a shaft. In many of the mines it was preferred that the men should go down in loops of rope, through which one leg was passed, and where the colliers, hanging on like a bunch of grapes, were, in the same way as the corves of coal, on arriving at the pit top, pulled over to the side by the banksman. Nay, it was an every-day practice both for men and boys to descend simply clinging to the rope with their legs twisted round it; and we have the evidence of Mr. Nicholas Wood, who had "frequently done so him-

self," that very few accidents could be traced to these methods of riding.* At the same period George Stephenson was aware that guide-rods had been adopted by Mr. Sparrow at Lane End, and that they had been employed in Yorkshire, but "thought that they were again disusing them." He had seen the employment of carriages in the mines of the south for bringing up the waggon which carries the coal, but thought it would only "do for a very small quantity."† His estimate was that the largest quantity brought up in a day, where three corves—making up a ton of coal—were raised at once, might be 300 tons.

What a surprising transformation is this, when we now, after only forty years' interval, look round and find every pit fitted with guides, either of wood or wire rope, or rolled-iron rails; the men riding in a smoothly-travelling cage, with a protecting iron shield overhead; and the velocity of the ascent of the greatly heavier loads as much as 600 yards in a minute!

The quantity which can thus be drawn at the central outlets of a colliery has kept pace with the improvements underground at which I have already glanced; and it is no uncommon performance for a pair of pits, or for four ropes working in one large pit, to raise from 900 to 1400 tons of coal in the day. The cages in these more extensive works, instead of being

* See Nicholas Wood, Evidence before Select Committee, 1835, p. 78.

† The result of prejudice against this system was that it was not till 1836 that a northern colliery, South Hetton, introduced the tubs and guides.

adapted to carry one tub, admit of a number of them, up to eight, being run into successive compartments, two-, three-, or four-decked cages. In order to lighten the load which has thus to be lifted, the ropes have for years past been made very generally of iron wire, in some cases of steel, and the cages themselves have been so closely looked to in this respect, that the largest used in the trade, constructed of thin steel bars, weigh no more than 24 cwt.

But in the hoisting through the deeper shafts, the weight of the rope is still a cause of difficulty. When its great length is considered, it will be seen that after passing the middle of the shaft, the descending empty cage will after a time, with the length of rope attached to it, begin to outweigh the full cage; and if this is to a great extent overcome by the use of the lighter modern ropes, there is still the great strain caused by the inertia of so heavy a weight at the beginning of the pull and the momentum that it acquires towards the end of the journey, which has to be counteracted.

In the main, three different methods of curing the evil have been adopted, which to a great extent may be regarded as being now on their trial. There is the varying radius, or leverage, of the drum, when a flat rope is employed, which coils always upon itself, and therefore gives the greatest radius to the drum, only when the weight is just about to be landed. The wear and tear, however, of a flat rope so applied has for several years been leading to a preference for round rope. If this latter be employed with a cylindrical drum, counterbalance chains passing over sheaves on

a high framing into an adjoining shallow pit, are found to do excellent service. A great weight is raised in these heavy chains at that portion of the winding where the engine has superfluous power, and hangs ready to assist in the pull, at the moment when the engine needs more power than usual. A third method is that of making the drum conical, and either lapping the rope regularly on a continuous conical wooden surface, or coiling it along an iron scroll channel fixed on the drum, and passing from a small diameter, when the load is first taken, to a large one at the conclusion of the lift.

The various modes of counterbalancing have recently formed the subject of an instructive paper in the 'Transactions of the Institute of Engineers of Newcastle,' by Mr. J. Daglish, who has in the past year been engaged in erecting what promises to be a much improved form of it at Silksworth, in the county of Durham.

A valuable adjunct in the matter of winding appears to be offered in a new apparatus lately brought before the same Institute by Mr. Fowler, and erected at Cinder Hill, near Nottingham, in which hydraulic power is employed to raise a system of elevating platforms, upon which the tubs are propelled by machinery to and from the cage, instead of the cage having to be lowered and raised as at present, whilst being loaded and unloaded.

Some of the larger engines employed for these winding purposes have come down to us from forty years ago; but they are for the most part changed, partly in

dimensions and partly also in type. The vertical cylinder, with condensing apparatus, is largely employed in the north, with diameters of from 50 inches to nearly 70 inches, and acting direct on the drum shaft; but in other districts a preference has been given of late years to coupled horizontal engines, with cylinders of from 24 to 48 inches diameter and stroke of 5 or 6 feet. Of large winding engines, with the steam used expansively, we shall soon hear more. In a suitable ratio the drums, or rope rolls, have attained diameters of 18, 20, or 24 feet, even as much as 30 feet at the maximum lap, and the pulleys over which the ropes pass—themselves 16 to 20 feet in diameter—are poised at 40, 50, or 60 feet high upon pit-head frames, which, with the entire heap-steads, are commonly fine examples of solid carpentry; or in numerous cases of late, notably at Seaton Delaval, Pemberton near Wigan, Monkwearmouth, Harton, and Silksworth, are structures of wrought iron, graceful in appearance, and giving good promise of extended durability.

It would be unjust to the ingenuity of inventors and the zeal of colliery managers, were I to omit some notice of the numerous contrivances which in the last twenty-eight years have been brought forward, for the prevention of the terrible accidents which are occasionally caused by the fracture of the rope. For some years past, it has been recognized that single-link chains are not to be relied upon where men are suffered to ride; and whilst three-linked chains have been largely used in the comparatively shallow pits of

central England, it has been a more common practice to employ flat ropes of hemp (or aloe fibre on the Continent), and since 1840, flat or round ropes of iron wire, and more recently of steel. The safety apparatus, or *parachute*, is applied to the cage, and consists of some form of clutches, or grips, which are brought into action on the parting of the rope, and which hold the cage against the guides. Several of these systems have been actually applied on a large scale, and I have seen many pits fitted with those of Fourdrinier, of White and Grant, Fontaine, Calow, Owen, and others. Without question, too, a number of lives have been saved by their successful action on the failure of the rope. But on the other hand, certain mishaps have been caused by their coming into play when not needed, whilst in other cases some portion has proved to be out of order when it was wanted; and it is objected, that if too great a reliance is placed upon them, less attention is apt to be bestowed on the actual rope. It is too certain that some of these inventions, though acting well when put up, have nevertheless, after trial of months or years, been again removed, and that to this day it is a moot question whether the introduction of even the best of them is desirable for pits where rapid winding is the rule, where steady experienced enginemen are employed, and where the tackling is duly examined from day to day.

To guard against another source of frightful accident, *overwinding*, or the pulling up of the load against the pit-head pulleys, a number of "safety hooks"

have been produced, intended to release the cage if raised too high, and leave it suspended upon a framing. The several detaching hooks of Messrs. Bryham, Ormerod, and Walker, all made to separate the rope from the cage when the main link comes to be jammed into a narrow collar, may now be seen in regular work at a number of our deepest and most extensive collieries.

Ventilation of Collieries.

It is notorious that the presence of explosive gas, or firedamp, in so many of our British coal mines, has been the cause of special attention being devoted to the subject of ventilation, and that the so-called "fiery" pits have led the way in the introduction of large bodies of atmospheric air into the workings by carefully planned arrangements, to which, perhaps, justice has scarcely been done by the public at large.

Wherever the evolution of gas is continuous and regular, it is obvious that the ventilating current ought to be ample enough to dilute it below the firing point, and to sweep it away; but where sudden outbursts are apt to take place, they may fill the workings, probably only for a short time, with so large a volume of inflammable mixture as to overpower any practicable amount of ventilating air, and render it indispensable to use the additional precaution of employing none but safety lamps. A sanguine, if not always judicious Government, in passing the Act of 1872, ignores this latter condition, and binds colliery managers to do that which is impossible, by requiring

that "an adequate amount of ventilation shall be constantly produced in every mine, to dilute and render harmless noxious gases." Unfortunately the annals of coal mining bring us acquainted with too many cases in which a good amount of ventilation was ordinarily kept up; but in which the cutting of a pent-up reservoir at a "trouble," or the release of gas from an upper seam on a fall of roof, or an up-burst from the floor of the coal, sometimes to the extent of thousands of cubic feet in a few minutes, has suddenly fouled a tract of workings and has ignited at some unprotected light. From the nature of the case, these heavy irruptions of gas are not frequent, but it is now sufficiently recognized that certain tracts, and particular seams, are never to be trusted to without a strict adherence to other safeguards besides a brisk ventilation. Truly, a severe test of preparation, and particularly of the men's discipline, may thus in a moment flash upon them; but we have had in the last few years several notable recorded instances where the danger has been suitably met, and has in a very short time passed entirely away, although lack of coolness and inattention to rules in the case of a single person would have involved all in destruction.

Although it has been so generally recognized that full active work and security can only be attained by the introduction of abundance of fresh air, there are districts where a prejudice against active ventilation has been fostered, probably in a great measure from the fear of spontaneous combustion, or "breeding fire," caused by the oxidation of the slack or refuse. And

sometimes it was held to be the best method of getting rid of firedamp, to ignite it purposely at fixed intervals when the men were away. Thus we have evidence that the Netherton mine, from the year 1798 and for years afterwards, had the gas in the workings fired by a fireline, in the morning at four o'clock, again at noon, and at seven in the evening. The part of the fireman was one of no little discomfort and risk—clad in coarse wetted flannel rags, and creeping along the floor towards the suspected place, and elevating his light at the end of a long pole into the uncertain dangers of the high workings of the thick coal. It is curious to observe the recurrence of old ideas in the suggestion laid before the Royal Society, within these last twelve months, of this dangerous and obsolete plan as a new way of putting an end to colliery accidents!

It was in the north of England that systematic contrivances for producing an air-current were first employed on a large scale. The large areas worked from a single centre of operations, the gaseous quality of the coal, and the even surface of the country in which the pits were sunk, to say nothing of the hard-headed character of the viewers, all contributed to this. Experiments were made in the early part of the century on fans and on air-pumps for colliery ventilation, which were accounted conclusive against the use of mechanical contrivances as compared with that of a furnace of due dimensions and suitably placed at the bottom of a deep and dry upcast shaft. A bold attempt was made, five and twenty years ago,

by Sir Goldsworthy Gurney and a parliamentary committee, to substitute jets of high-pressure steam for the furnace, and some picturesque letters in the 'Times' went far towards carrying public opinion in the same direction; but the steady comparative trials made at various Northumbrian and Durham pits only established more firmly the character of the furnace, notwithstanding much that had been doing abroad and in some other parts of the kingdom to introduce other methods. Thus the great air-pump cylinders of Mr. Struve were erected in considerable numbers in South Wales; and Nasmyth, Biram, and Brunton tried their several varieties of fan, of diameters up to 14 feet and 16 feet. But the more prominent of experienced viewers adhered unflinchingly to the furnace, which, however much it might be proved wasteful of fuel, had accomplished a more powerful ventilation than any other contrivance. And such improved furnaces as those of Hetton, Monkwearmouth, and the Green Pit, Ruabon, have given a volume of air suitable to the largest acreage of workings. Whilst Buddle, in 1835, said that his standard air-courses varied from 2000 to 3800 cubic feet per minute, and that he considered the Wallsend workings in a perfectly safe state with 5000 cubic feet of air per minute; certain other collieries, as Pensher, were said to give off at the upcast from 30,000 to 50,000. In the last few years such improvements have been made, by increasing the number of *splits*, or separate currents, reducing the length of the runs, enlarging the air-ways, and employing the best construction for the furnace, that

our larger works will now give an aggregate of from 120,000 to 250,000 cubic feet passed through the shafts in a minute. Another somewhat unexpected change of views has taken place, and since the London Exhibition of 1862, when M. Guibal, of Mons, sent in a drawing of his ventilating fan, the application of the centrifugal ventilators, especially in shafts of moderate depth, has made great way; and whilst those of Waddell and Guibal have in very numerous cases been erected of 30 feet diameter, the "Guibals" have at several important collieries attained gigantic dimensions—36 to 45 feet diameter—with a breadth of 12 feet to 14 feet, and a performance so economical as to make up within a brief period for the somewhat heavy expenses of cost and erection of casing-house and outlet stack.

It is curious in a retrospective glance to observe how this change accords with the strongly expressed views of a genius in another profession, the late John Martin the artist, who, in 1835, came forward as a volunteer witness, and warmly advocated the use of exhausting fans worked by steam power.

One great objection to which the underground furnace is liable, is the danger of the "returns" being fouled to the firing point, and in this state coming in contact with the burning coals. It used half a century ago to be no unfrequent sight to see the flames of the burning gas playing over the surface, and great watchfulness had to be exerted to put out the fire with the aid of water, in the case of the returns being seriously loaded with firedamp. The presence of mind needed

under such circumstances is well illustrated by the action of Hall, the underviewer at Jarrow, who, when the furnace at the West Pit fired the return, and the men about the place gave themselves up for lost, instantly started forward and threw open the main doors in the rear of the burning current. Thus he at once not only cut short the whole of the ventilation, but isolated and drove the burning part of the "returns" away up the shaft.

The employment of a *dumb drift*, or separate channel, for the more risky returns, mouthing into the shaft at a higher point than the furnace, has to a great extent done away with this source of danger.

Mere figures might of course be deceptive; and the large volumes of air of which I have spoken would be of no value to the mine, unless they served as a measure of what actually passes through the inner recesses, and not only what descends and ascends through the down- and up-cast pits. There is in this point of view a great diversity, produced in part by the different plans of laying out the work to which I have before adverted, and in part also by the care and cost bestowed on the arrangement of the air-ways, and the sundry apparatus of stoppings, doors, sheets, brattices, and crossings, by which the ventilation is carried on. It is unnecessary to refer to the details of small and unimportant works which serve no one as a model, but when we look back for a few years and find that in the larger collieries—as soon as it was recognized that the ventilating current ought to be coursed through the whole of the workings—that current

came to be 20 or 30 miles in length, occupying many hours on its journey between the entrance and the exit, it appeared theoretically and in practice that a great benefit would be to shorten it. This reduction then of the length of the air-courses is combined with their multiplication, and with the treatment of each main split as airing a different district; and although crossings (by which one current of air is conveyed over another) are multiplied, the number of doors—very vulnerable points as they are in the security of the fabric—is greatly lessened. Thus the total quantity of the air has been materially increased, and its freshness as brought to the working faces much improved, whilst the return air is now secluded from the ordinary traffic of the mine. The advancement in the fixing of the principles and in the practical conduct of the ventilation has fully kept pace with the increase of the output, and I believe that we may look with much satisfaction on the statistics of the Government inspectors, which show that the total number of accidents per annum has not increased, although the entire production of the country is in round numbers half as much again as it was, when the system of inspection was fully established.

QUARRIES AND BUILDING STONES.

By Professor Hull, F.R.S. (Director of the Geological Survey of Ireland).

In commencing the account of the building stones quarried in Great Britain and Ireland, it will be in accordance with precedent, and the prestige attaching to the rock itself, to commence with granite, if not the oldest, certainly the noblest of all rocks. From this granite basis I shall proceed with a superstructure of the other crystalline rocks used in building, crowning the edifice with those layers of sedimentary strata, the limestones and sandstones of the different formations, from the oldest to the most recent. And in treating this subject I shall consider it generally under three heads, though not necessarily always in exactly the same order, viz.:

1. Mineral characters of the building stones in their natural state.
2. Geological position and enumeration of the principal quarries, where they are worked.
3. Examples and illustrations of their use.

Granite is a crystalline granular compound of silica, felspar, and mica, in which the silica (or quartz) generally occurs in an amorphous state, as a cement binding together the crystals of felspar and mica. With this constitution, it is clear that the silica has been the last of the minerals to solidify, though the most difficult to fuse; hence it is inferred that some other agent was

present, such as water at high pressure and temperature, owing to which the silica was retained in a state of plasticity, until the felspar and mica had opportunity to enter into a crystalline state.

Some granites are ternary compounds, but more generally they are quaternary and even quinary, consisting of silica, two varieties of felspar, or two varieties of mica. When two felspars are present, as in some of the granites of Galway, Donegal, and Aberdeenshire, they consist of orthoclase and oligoclase; or, as in the case of that of the Mourne mountains in Downshire, of orthoclase and albite. When two micas occur, they are generally black and grey varieties, as in the granite of Wicklow.

All granites have been formed at a high temperature and pressure, and are either of intrusive (or irruptive) or metamorphic origin. When intrusive they are generally amorphous, though often traversed by parallel planes of jointage resembling those of bedding, and when metamorphic, are usually foliated; that is, the flakes of mica are arranged in parallel layers, resembling leaves; hence the term.

Granites are generally highly silicated, the proportion varying from 65 to 80 per cent. They vary much in hardness, being often exceedingly tough, but in some places, owing to the decomposition of the felspar or the mica, being sufficiently soft to admit of being dug out with a spade. Great care is therefore always necessary in the selection of granite for building purposes, and close observation of the behaviour of the natural exposed surface of the rock in presence

of the atmosphere. Its specific gravity is about 2·6; a cubic foot weighs about 166 lb., and a cubic yard, as nearly as possible, 2 tons. It contains from 0·5 to 1·3 per cent. of water; in other words, a cubic yard of 2 tons contains, in its ordinary state, about 3·5 gallons of water, and is capable of absorbing nearly a gallon more on being immersed in pure water for a short time. Its power to resist crushing forces varies much. Mr. Mallet, C.E., having found cubes of one inch of granite, from various parts of Ireland, to withstand weights varying from 2310 up to 13,400 lb.

Granite generally occurs in a massive state, and traversed by joints which facilitate the extraction of the stone in large blocks; hence it is frequently employed in structures of a massive character, which are intended to resist shocks or pressure, or for foundation stones for ordinary buildings. Owing to the size and solidity of the blocks which the granites of some districts afford, they are well suited for voussoirs of arches, piers of bridges, pillars, monoliths, docks, and lighthouses. The observations made on the conduct of granite buildings at Boston and Chicago, U.S., appear to show that it is apt to fly and splinter under fire.

The granites of the British Isles are of various geological ages, from the Silurian down to the Permian, or possibly Jurassic, while amongst the Alps and Pyrenees foliated granites of still more recent age are found.

Illustrations of use of various Granites.—The granite districts of England are found in Devon and Cornwall, the Channel Islands, Lundy Island, Mount Sorel in

TABLE OF EXPERIMENTS ON GRANITE.

Name.	Weight of each Specimen.	Surface exposed to Pressure.	Pressure required to fracture Stone.			Pressure required to crush the Stone.			Observations.
			Total.	Per Superficial Inch of Surface.	Average per Superficial Inch.	Total.	Per Superficial Inch of Surface.	Average per Superficial Inch.	
	lb. oz.	sup. in.	tons	tons	tons	tons	tons	tons	
Herm	6 6	16	80·0	5·00	4·77	116·0	7·25	6·64	
	6 6	16	72·5	4·53		96·4	6·03		
Aberdeen (grey)	5 0	17	81·0	4·76	4·13	85·5	5·03	4·64	
	5 1½	18	63·0	3·50		76·5	4·25		
Heytor	4 7	16	67·5	4·22	3·94	103·5	6·47	6·19	
	4 8	16	58·5	3·66		94·5	5·91		
Dartmoor	4 10	16	67·5	2·22	3·52	103·5	6·47	5·48	
	4 8	16	45·0	2·81		72·0	4·50		
Peterhead	5 5	18	58·5	3·25	2·88	94·5	5·25	4·88	Red granite.
	4 12	18	45·0	2·50		81·0	4·50		
Peterhead	5 3½	18·6	58·5	3·14	2·86	85·5	4·60	4·36	Bluish grey.
	5 4	17·5	45·0	2·57		72·0	4·11		
Penryn	5 7	13·5	63·0	3·41	2·58	72·0	3·90	3·45	
	5 4	18·0	31·5	1·75		54·0	3·00		
Killiney	..	9·0	..	..	..	..	4·81	..	Grey felspathic.
Ballyknocken ..	..	9·0	..	..	..	..	1·43	..	Coarse grey.
Ballybeg (Carlow)	..	9·0	..	..	..	..	2·20 4·14	3·17	Grey felspathic.

Leicestershire, Shap in Cumberland, in the Isles of Anglesea and of Man.

The granite of Devon and Cornwall is of several varieties. At Dartmoor it has a prevailing greyish hue, and is sometimes porphyritic. It is quarried at Blakenstone and at Hingston Down, and is shipped in large quantities from Looe. Quarries have also been opened at Tremator, near Tavistock. The granites of Cornwall are frequently schorlaceous and porphyritic, as at Land's End. The principal quarries being at Cheesewring, near Liskeard; Lamorna, west of Penzance; Penryn, near Falmouth; and Mill Hill, Maldron.

The granite of Devon and Cornwall has been largely used in London and other cities. The London Docks, Westminster, Waterloo, and London bridges, the Thames Embankment, are amongst some of the structures in which it has been employed. It has also been used in the Portland Breakwater, the Keyham Docks, the Birkenhead Docks, and the Wellington Monument, Strathfieldsaye.

The syenitic granite of Mount Sorel is a hard and durable stone, of a rich pink colour, and is esteemed in London for ornamental purposes. It is also largely used as a paving stone.

The porphyritic granite of Wasdale Crag, near Shap, in Cumberland, is a very handsome stone, and is now largely quarried, cut and polished for pillars, pilasters, corner stones, and monuments, at works situated near the locality itself. The texture is somewhat variable; but in general it consists of a reddish crystalline *granular* base of quartz, felspar, and black mica, in

which large flesh-coloured orthoclase crystals are imbedded. It has a strong resemblance to the celebrated red granite of Egypt.

The principal granite quarries of Scotland are those of Aberdeen, Peterhead, the Isle of Mull, Craignair and Creetown in Kirkcudbrightshire. The granite of Aberdeen is of a greyish tint, and is quarried for structural and ornamental purposes, as it takes a fine polish; but that of Peterhead is of a rich red or pink colour, and is highly prized for ornamental purposes, such as columns, tesselated pavements, pilasters, cornices, &c. It takes a high polish, and can be extracted in large blocks, so that there are few ornamental stones of more general use in Britain, and even in some parts of America, to which country large quantities are annually exported. Some good examples of its use are seen in the pillars of Carlton Club House, the Fishmongers' Hall, London, and the columns of the interior of St. George's Hall, Liverpool.

The granite of Mull is of a fine reddish or pink colour, and is now cut and polished on the spot at the works of the Scottish Granite Company. From this island it was proposed to extract a monolith, similar to those of ancient Egypt, to be erected to the memory of the late Prince Consort, but the project was abandoned. The granite of Kirkcudbrightshire is generally of a greyish colour and porphyritic. It has been largely used for public works at Liverpool, Manchester, and other towns of the north of England.

Granite also occurs in the Island of Arran, at Strontian and in several parts of the Grampian mountains.

The *granite* districts of Ireland are situated in

Wicklow, Galway, Donegal, and Down. That of Wicklow and Down is of a greyish tint, and has been extensively quarried both at Kingstown, Newry, and Castlewellan. Donegal produces a beautiful red granite, equal in beauty to that of Peterhead, and capable of receiving a high polish.

Granite has been used from the most ancient periods. From the quarries of Egypt were hewn those noble monolithic pillars, or obelisks, which have been carried from their ancient sites to adorn the cities of Europe. Columns of this rock are also found amongst the ruins of Roman Tyre; and two of these, one of grey and the other of red varieties, adorn the Piazza of Venice.

Greenstones, &c.—The large group of igneous rocks, allied to granite by origin, and known as basalts, whinstones, and greenstones, are ill adapted for building purposes, owing to their extreme hardness, and sombreness of colour. Basalt, with its more largely crystalline granular variety of dolerite, is a rock formed of labradorite, felspar, augite, and titano-ferrite; while greenstone or diorite is composed of hornblende and felspar. Their principal uses are for paving and road metalling, and for these purposes they are largely employed in Manchester, Liverpool, and other large towns of the north of England and of Scotland. The most important quarries are those of Bardon Hill in Leicestershire, and of Penmaenmawr in North Wales, from which latter place enormous quantities of squared "sets" are annually sent by ship and rail to various towns of England and Ireland for use as paving stones.

LIMESTONES.

The limestones of Britain used as building materials are derived from the Devonian, Carboniferous, Permian, Oolitic, and Cretaceous formations, though but sparingly from the last. They are all stratified rocks formed in water, either from the shells and stony skeletons of marine animals, or by precipitation of calcareous matter in inland seas. I shall consider each of these in the order above named, that is to say, beginning with the oldest and ending with the newest.

Devonian Limestones.—These limestones are derived from a formation taking its name from Devonshire. They occur in massive, but more or less lenticular, beds of reddish, grey, or yellow colours with veins of white calc-spar, and are sometimes coralline, yielding "madrepore marbles." More often they are crystalline, and are largely quarried for marble, as they take an excellent polish, presenting warm and pleasing varieties of colour. The principal quarries are at Oreston, near Plymouth, which furnished stone for the Plymouth Breakwater. This, however, it was found necessary to replace by granite where under the water-line, as the limestone became honeycombed by the operation of boring molluscs. Other quarries are at Pitit Tor, near Babbacombe, and Newton Bushell. The stone quarried at Ipplepen yields blocks 18 feet square, and is used for ornamental purposes in London. In North Devon there are limestones and marbles belonging to the same formation at Bridestow, South Tawton, and Drewsteignton, while black marbles with white veins

of calc-spar are found at Chudleigh, Staverton, and Berry Pomeroy.

The great calcareous formation of the Carboniferous limestone occupies large tracts of the north of England, as well as of Somersetshire, South Wales, and Monmouth, and the border counties of North Wales. Being generally of a hard, brittle, shelly or crystalline nature, and not of a pleasing colour for street architecture, it is more extensively quarried for lime, cement, and iron-smelting purposes than for building. Derbyshire produces marbles of dark-grey or bluish colours, and either coralline, crinoidal, or shelly, according to the varieties of the fossil remains enclosed. The black marbles are generally derived from the upper beds, consisting of carbonaceous limestones interstratified with black shales, but the great mass of the formation is made up of stony shells and skeletons of marine animals, often in a broken and fragmentary state and bound together into a solid mass by calcareous cement.

Along with the beds of limestone are others of dolomite and of silicious chert, a flinty material used in the manufacture of china ware. There are large quarries at Crich, Matlock, Buxton, Wirksworth, and the flanks of the Weaver Hills. There are marble-polishing works at Ashford, Bakewell, and Derby.

Permian Limestone.—This is the well-known magnesian limestone, or dolomite of the north-east of England, and is very dissimilar to the limestone of the underlying formations above described, being of a softer and more granular texture, easily moulded, and of a pleasing yellowish colour—well suited for street

architecture. Like all limestones, however, and especially those of a less crystalline structure, it is liable to rapid decay under a dripping sky when combined with a smoky or gaseous atmosphere, and of this the new Houses of Parliament in Westminster afford an unhappy illustration.

The stone is moderately soft, is easily moulded with the chisel, granular to compact, and sometimes crystalline in structure. The blocks require great care in selection at the quarry.

The magnesian limestone ranges in a northern direction from Nottingham to Tynemouth, being, however, interrupted for a short distance in the vicinity of North Allerton. It has a total thickness varying from 300 to 600 feet, and is separated into an upper and lower division near Mansfield by the interposition of marly strata. In this district the rock contains a large proportion of silica, as will appear from the following analysis by Mr. Richard Phillips :—

White and Red Silicious Dolomites of Mansfield.

	White.	Roseate.
Silica	51·40	49·40
Carbonate of lime	26·50	26·50
Carbonate of magnesia	17·98	16·10
Iron, alumina	1·32	3·20
Water and loss	2·80	4·80
	100·00	100·00

The Mansfield stone is of good quality, and is largely employed for building and paving, as well as

for making troughs and cisterns. In the Mansfield Woodhouse, and Bolsover stone the proportion of silica is only about 4 per cent., and the stone approaches more nearly to a pure dolomite. The specific gravity of the Bolsover stone is 2·316; the weight of a cube of 2 inches, 4890·8 grains in the ordinary state; when dried, 4881·4 grains; when saturated with water, 5042 grains; from which it will be seen that the stone is highly absorbent. On the whole, the magnesian limestone is a stone subject to rapid variations in mineral composition, the proportions of silica, lime, and magnesia frequently varying and influencing the durability of the rock as a building stone.

The stone from Mansfield Woodhouse quarries has been used in the lower portions of the new Houses of Parliament, and in the construction of the Martyrs' Memorial at Oxford. The stone from Anston quarries, Yorkshire, is of good quality, and is used in the frontage of the Museum of Practical Geology, London. The choir of Southwell Church, of the twelfth century, of Mansfield stone, is in good preservation; as are also Tickhill Church, of the fifteenth century; Huddlestone Church, of the same date; and Huddlestone Hall, a century later. Other important quarries in magnesian limestone are situated at Brodsworth, Cadeby, and Park Nook, near Doncaster; and Smawse, near Tadcaster. The keep of Conisborough Castle, the ancient Saxon stronghold, which is the scene of some of the stirring events in 'Ivanhoe,' is in good preservation, and is perhaps the oldest building of magnesian limestone in the north of England. On

the other hand, the Minster and churches of York, Howden, and Doncaster old church, have suffered severely from atmospheric influences.

The *Oolitic*, or *Jurassic Limestone* rocks are largely employed for building purposes, and yield a stone susceptible of the most delicate sculpturing; of moderate hardness and durability; either white, or coloured with delicate shades of yellow, and consequently admirably adapted for street architecture or ecclesiastical buildings.

The formation to which these limestones belong ranges from Dorsetshire into Yorkshire, through Somersetshire, Gloucestershire, Oxfordshire, Northamptonshire, and Lincolnshire, and is largely quarried throughout its course. It is interposed between the Lias and the Cretaceous rocks, and consists of four divisions of limestone: — 1, the Inferior oolite; 2, the Great, or Bath oolite; 3, the Coralline oolite; and 4, the Portland limestone. Each of these is separated by great beds of clay, and the whole formation is highly fossiliferous.

Commencing with the lowest of these limestone divisions, is the *Inferior Oolite.*

We find this stone chiefly developed in Gloucestershire, where it forms the plateau of the Cotteswold Hills, overlooking the vale of the Severn. At Leckhampton Hill quarries it attains a thickness of 264 feet, consisting of several varieties, the best building stone being situated near the centre. This is a fine-grained, compact oolitic freestone, white or light yellow, slightly shelly, and yielding blocks of con-

siderable size. When first extracted it is sufficiently soft to be cut with the saw, but hardens on exposure. It is composed of little spherules of lime, either hollow or enclosing a grain of sand or fragment of shell, bound together by a calcareous cement, and it is from these spherules that the stone derives its name of "oolite." It has been used in the construction of Gloucester Cathedral, Tewkesbury Abbey Church, Cheltenham parish church, and many fine Tudor mansions. Unless acted on by a smoky atmosphere, it is fairly durable, but yields easily to acids. Quarries have been opened at Cleeve Cloud, Broadway, Syreford, Brockhampton, and Painswick; the stone from this quarry being almost as finely granular as that of Caen in Normandy, which it resembles.

Bath Oolite is the best known and most largely exported of the oolitic freestones. There is very little difference, however, between it and the stone of Cheltenham and Painswick, either in colour, texture, or composition. It consists of fine-grained oolitic limestone, white or cream-coloured, sometimes shelly, and when first quarried, sufficiently soft to be cut by the saw, but afterwards hardening on exposure. The principal quarries are at the Box escarpment, some of which have been worked for several hundred years. The weather bed of the quarry is generally used for plinths, string courses, cornices; the "corn-grit" for dressings; while the "scallet," which is the finest in grain, is used for ashlar. From these quarries the stone for many of the most beautiful structures in the West of England has been extracted; amongst which

may be mentioned Glastonbury Abbey Church (eleventh century), Wells Cathedral (twelfth to fifteenth centuries), and the Abbey Church of Bath (1526). The analysis of the stone from Box gives on an average: carbonate of lime, 94·52; carbonate of magnesia, 2·50; iron and alumina, 1·20; water and loss, 1·78; bitumen, a trace.

At Oxford the oolitic freestone from Tainton and Burford has been largely used in structures belonging to the twelfth and three following centuries, and has stood remarkably well. The more modern buildings have been constructed for the most part of Headington stone, belonging to the Coralline oolite, which is of inferior durability. The stone from the Tainton, Box, and other quarries is often extracted by tunnelling, and is so soft when first taken from its bed that it may be cut by the saw, but afterwards hardens on exposure.

The shelly oolitic limestones of Northamptonshire and Lincolnshire, formerly considered to belong to the Bath, or Great oolite, are now classed by some geologists with the Inferior oolite. The principal quarries are those of Barnac, Kelton, and Casterton, in the former county, and of Haydor and Ancaster in the latter. These oolites have been used in the building of the beautiful ecclesiastical structures of this part of England, including Lincoln Minster, and in general have stood well. Amongst private residences built of oolite in the same district, may be mentioned Wollaton Hall and Belvoir Castle.

Byland Abbey, of the twelfth century, offers a good illustration of the use of the Yorkshire oolites. Built

partly of silicious grit, and partly of oolite (chiefly in the exterior), from the Wass quarries in the vicinity, the west front, which is of oolite, and is ornamented with the dog-tooth and other decorations, is in perfect condition.

Portland Stone appears only to have come into general use as a building material within the last two hundred years. It seems first to have been brought prominently into notice by Inigo Jones, who cased the outside of old St. Paul's with this material, and added a grand Corinthian portico to the west front. It was still more largely employed, however, during the reign of Queen Anne; and with it have been constructed London's great Cathedral (1700), most of the London churches of that age, the old Westminster and Blackfriars bridges, the Custom House, and Goldsmiths' Hall; whilst most of the fine buildings of the city of Dublin, such as the Bank of Ireland, Trinity College, the Four Courts, and Custom House, are to a large extent constructed of stone brought from the Portland quarries, and in which the large shells characteristic of this rock can be easily identified.

Portland stone is nearly pure limestone, but contains a little silica and magnesia. It is also denser than the oolitic limestones, weighing from 135 lb. to 147 lb. per cubic foot; this imparts to it a hardness and durability superior to that of the oolitic limestones in the presence of a smoky atmosphere. Owing, however, to occasional flaws, and the presence of large shells, it is not so well fitted for the delicate carvings of the interiors of churches or mansions. The prin-

cipal quarries are those of the Isle of Portland in Dorsetshire, which present a vertical face of from 43 feet to 52 feet—not, however, all consisting of workable stone. The principal layer is called the White Bed, which varies from 5 feet to 8 feet in thickness. The bottom bed is somewhat thicker. Kentish rag has now largely replaced Portland stone as a building material in London.

To the oolitic limestone series belongs the celebrated Caen stone, obtained from quarries in Normandy. It is a beautiful nearly white stone—sufficiently soft to be easily worked by the chisel; but especially in the interior of buildings sufficiently durable, and well fitted by its uniform and fine-grained texture to receive the most delicate sculpturing. It has been used in England from the time of the Norman Conquest and downwards, and in Ireland from a possibly still more ancient period.

Kentish Rag.—This building stone, recently introduced into the London district, is obtained from the Lower Greensand formation near Hythe and Folkestone. It is a kind of calcareous sandstone, of light yellow or brown colours, and often shelly. The principal quarries are at Godstone, Maidstone, and Boughton.

The Lower Greensand is the newest formation, producing calcareous sandstones of much value in architecture.

The White Chalk of the south and east of England is seldom sufficiently hard and solid to be used for building purposes, except within the interior of build-

	MAGNESIAN LIMESTONES.				OOLITES.				LIMESTONES.		
	Bolsover.	Huddlestone.	Roach Abbey.	Park Nook.	Ancaster.	Bath, Box.	Portland.	Ketton.	Barnack.	Chilmark.	Hamhill.
Silica	3·6	2·53	0·8	0·0	0·0	0·0	1·20	0·0	0·0	10·4	4·7
Carb. of lime ..	51·1	54·19	57·5	55·7	93·59	94·52	95·16	92·17	93·4	79·0	79·3
Carb. of magnesia	40·2	41·37	39·4	41·6	2·90	2·50	1·20	4·10	3·8	3·7	5·2
Iron, alumina ..	1·8	0·30	0·7	0·4	0·80	1·20	0·50	0·90	1·3	2·0	8·3
Water and loss ..	3·3	1·61	1·6	2·3	2·71	1·78	1·94	2·83	1·5	4·2	2·5
Specific Gravities.											
Of dry masses ..	2·316	2·147	2·134	2·138	2·182	1·839	2·145	2·045	2·094	2·481	2·260
Of particles	2·833	2·867	2·840	2·847	2·687	2·675	2·702	2·706	2·627	2·621	2·695
*Absorbent Powers when Saturated.**											
Cubes 2-inch sides	0·151	0·239	0·248	0·249	0·180	0·312	0·206	0·244	0·204	0·053	0·147
Cohesive Powers.											
In lb. per sq. inch	8307	2531	3905	3531	2343	1492	2130	2556	1775	7171	4047

* In this Table the bulk of the stone (inch cubes) is considered as unity.

ings. In this position it has been used with success in some old ecclesiastical structures, such as St. Alban's Abbey Church, and some of the older portions of Windsor Castle.

Amongst the limestones of the Tertiary series of the south of England, the most important is that derived from the Bembridge series in the Isle of Wight. This band rises conspicuously along the shore of Whitecliff Bay, with an average thickness of about 5 feet. It is of a yellowish colour, rather soft, and charged with fresh-water shells, and has been used to a considerable extent in structures of the Island and of the south of England.

The Table on the preceding page gives results of experiments on some of the better-known building limestones, as determined by the Commissioners appointed to select the stone for the new Houses of Parliament.

Sandstones.

The British sandstones used in building are derived from the Silurian, Devonian or Old Red Sandstone, Carboniferous, and Triassic or New Red Sandstone, formations. Those, however, of the Silurian series, lying either too remote from the busy centres of industry, or not being of an agreeable colour, are seldom used beyond the immediate localities where they occur, either in Wales, Salop, Cumberland, or the Uplands of Scotland. They may therefore be dismissed with the single remark, that owing to their extreme hardness they are not well suited for the more ornate kinds of building; they furnish, however, good materials where strength is the main object.

Devonian, and Old Red Sandstone.—The sandstones of this group are distributed throughout Devonshire, Herefordshire, and Monmouthshire in England, and various parts of the south and north-east of Scotland. They are of various degrees of coarseness, from the finest grain up to conglomerates of large rounded boulders, such as are found in Cantyre and along the southern slopes of the Grampians. The colours vary through red, purple, and yellow, to light green or grey; but sometimes the stone is almost white.

In Devonshire, building sandstones occur at the Hangman Hills, the Foreland, North Hill, and Newnham Park. From the quarries north of the Severn, in the vicinity, portions of Chepstow Castle, of the eleventh and twelfth centuries, have been built and are much decomposed. Tintern Abbey (thirteenth century), built of red and grey sandstones of this formation—sometimes laminated—has in some places well resisted the attacks of time; and it is to be feared that the hand of man has been the most powerful agent in the dilapidation of this graceful structure.

The Old Red Sandstone of Scotland produces the well-known sandstones and flags of Arbroath and Dundee—which are largely used in Edinburgh, Glasgow, London, and other large towns. The flagstones of Caithness, Cromarty, and Nairn are also used for paving and building. The flagstones of Arbroath are of a light greenish-grey colour, of dense structure, and resist the weather successfully.

Carboniferous Sandstones.—These are very largely used for building and paving purposes in the north of

England and Scotland, and are generally hard and durable, of yellowish or greyish tints, and various degrees of coarseness. They are derived from the millstone grit and coal measures in England, and in Scotland from the calciferous sandstone series as well, which lies near the base of the Carboniferous system of rocks.

The millstone grit produces either massive coarse-grained blocks, suited for foundation stones, engine beds, voussoirs of bridges, &c.; or finer laminated grits, which may be used for ashlar, flagstone, or paving. Of this stone many of the public buildings in Manchester, Blackburn, Leeds, Bradford, and other large towns of the north of England are built; and as it resists the action of the acid contained in the smoky atmosphere of these towns, it is well suited for the purpose. Some of the quarries in the counties of Lancaster, Stafford, Cheshire, Derby, and York are of large size, and of these may be specially mentioned the following: Parbold, Harrock Hill, Longridge Fell, Haslingden, and Rossendale, in Lancashire; Baddeley Edge and Wetley, in Staffordshire; Congleton, in Cheshire; Bakewell Edge, Stancliffe, and Duffield Bank, in Derbyshire; Aislaby, Meanwood, and Stanningley, in Yorkshire; and Stenton, in Durham. Viney Hill, in Gloucestershire, also produces a similar stone.

From the lower part of the coal formation excellent flagstones are obtained in Cheshire, near Macclesfield; Lancashire, near Wigan, Burnley, and St. Helen's; and Elland, in Yorkshire. These are not only used in the neighbouring towns, but sent to all parts of England.

The sandstones of the coal measures are seldom durable, and generally become iron-stained on exposure, owing to their containing considerable quantities of iron and alumina. The quarries of Heddon and Kenton, near Newcastle, are of this kind, as will be seen from the analyses below.

Analyses of Sandstones.—The following analyses, with the results of experiments on specimens of sandstones, are taken from the Commissioners' Report, 1839:—

Analyses, &c., of Sandstones.

	Craig-leith.	Darley Dale.	Heddon.	Kenton.	Mansfield.
Silica	98·3	96·4	95·1	93·1	49·4
Carb. of lime ..	1·1	0·3	0·8	2·0	26·5
Carb. of magnesia	0·0	0·0	0·0	0·0	16·1
Iron, alumina ..	0·6	1·3	2·3	4·4	3·2
Water and loss ..	0·0	1·9	1·8	0·5	4·8
Specific Gravities.					
Of dry masses ..	2·232	2·628	2·229	2·247	2·338
Of particles	2·646	2·993	2·643	2·625	2·756
Absorbent Powers.					
Proportions of 2-inch cubes.	0·143	..	0·156	0·143	0·151
Cohesive Powers.					
In lb. per square inch.	7881	7100	3976	4970	5112

Permian Formation.—The sandstones of this formation are rarely used for building purposes, except in Cumberland, where they are of a firmer consistency than in other parts of the country. The rich valley of the Eden is for the most part formed of this sandstone, and it has been used in structures both of ancient and modern date in the town of Penrith, and of Furness and Calder abbeys. The colour is deep red, and presents a rich and pleasing contrast to the foliage around.

New Red Sandstone.—The stone of this formation has been largely used for building purposes in Liverpool, Chester, Shrewsbury, Stafford, and many of the towns and villages of the central counties. The Bunter sandstone, which forms the lower division, is only occasionally suited for any but very rough and ordinary buildings, as it is either too soft or too pebbly. In the neighbourhood of Liverpool and Birkenhead, however, it assumes a more compact character, and has been used with good effect even in the more ornate buildings. The colour is light brownish-red, and the stone is quarried extensively along the high ridge of Everton, Kirkdale, West Derby, and Roby.

A better building material, however, is obtained from the lower portion of the Keuper division, and this has been extensively used in the older ecclesiastical structures of the central and western counties. The formation ranges from the banks of the Mersey, near Runcorn, through the Delamere and Peckforton hills to Grinshill, near Shrewsbury, and is extensively distributed through parts of Staffordshire, Worcestershire, and Warwickshire. The stone is generally

compact, uniform in texture, easily worked, and of light red, brown, or greyish colours to white. It can often be quarried in large blocks, and stands the weather well. With this stone the recent restorations of Worcester and Chester cathedrals have been effected, and its capability of receiving delicate mouldings and sculpturings, as well as of affording a material agreeable to the eye, is exhibited in the case of these buildings. The stone is quarried (amongst other places too numerous to mention) at Bidston Hill, Helsby, Manley, Storeton Hill, and Wallasey, in Cheshire; Belton, Grinshill, and Weston, in Salop; Colwich, Colton Mill, Crumpwood near Alton, Fulford, Hollington, Tixall, and Weston, in Staffordshire; and Ombersley and Hadley, in Worcestershire, from which quarry the stone now employed in the restoration of Worcester Cathedral is obtained. This stone has been strangely overlooked by the Commissioners in their Report; but it seems to me that some quarries in this formation were capable of yielding material well suited for the Houses of Parliament at Westminster.

Jurassic, or Oolitic Sandstone of Yorkshire.—In that part of Yorkshire stretching inland from the coast of Whitby and Scarborough, the Jurassic formation contains numerous beds of yellowish and brownish sandstones, which are sometimes used for building purposes. The principal quarry is one near Aislaby, where the workable stone is 46 feet in thickness. It has been used in Whitby Abbey, New University Library at Cambridge, and Scarborough and Bridlington piers.

Wealden Sandstone of Tunbridge Wells.—This stone is only locally in demand; it is of a brownish colour, rather soft, and occurs in beds, varying from 1 to nearly 4 feet in thickness. It belongs to the great group of strata known as "the Wealden," and is quarried at Calverley, near Tunbridge Wells.

Statistical Returns of Quarries.

In 1860 was published an elaborate return of the quantities of clays, bricks, building and ornamental stones, &c., raised and manufactured in the year 1858, prepared by Mr. R. Hunt, F.R.S., and published in the "Mineral Statistics" of the United Kingdom. Since then no further returns have been obtained; but those for the year 1858 are probably only a little under the amount of similar materials now being used, and are as follows:—

General Summary of the Production of Building and other Stones in the United Kingdom of Great Britain and Ireland.

	Estimated Total in Tons Returned.	Computed Total of entire Production.	Value of Computed Total.
			£
England	3,935,939	7,500,000	1,705,508
Wales	1,229,863	3,500,000	898,123
Scotland	855,888	4,750,000	1,211,393
Jersey	..	14,200	7,900
	..	15,764,200	3,822,924

The number of quarries from which returns were received: in England, 1504; in Wales, 158; in Scot-

land, 678; in Jersey, 8. From Ireland 667, but returns of the quantity of stone could not be obtained of a satisfactory nature; and the number of quarries for the United Kingdom given above falls far short of the reality.

Books of Reference.—Hull's 'Building and Ornamental Stones of Great Britain and Foreign Countries' (London), 1872. Sir J. Burgoyne's 'Rudimentary Treatise on Blasting and Quarrying,' Weale's Series (London), 1849. Château's 'Technologie du Bâtiment' (Paris). Wilkinson's 'Geology and Ancient Architecture of Ireland' (London), 1845. Gwilt's 'Encyclopedia of Architecture,' edit. 1873 (London). B. von Cotta, 'Rocks Classified,' &c., Eng. Vers. Macculloch's 'Classification of Rocks' (London), 1821. "Observations on Stone used for Building," by C. H. Smith, 'Trans. Roy. Inst. Brit. Architects,' 1842. 'Report with Reference to the Selection of Stone for the New Houses of Parliament,' addressed to the Commissioners of H.M. Woods, Forests, &c. (1839).

EXPLOSIVE COMPOUNDS.

By W. Mattieu Williams, F.R.A.S., F.C.S.

Among the earliest and most ingenious mechanical inventions of primitive human beings, are those devoted to the purpose of throwing disagreeable things at each other. Many laconic definitions of humanity have been offered, and I may yet propose another, viz. that man is an animal that throws stones. The projectile propensity is displayed by men of all nations and at all periods of life. No amount of remonstrance or flogging prevents an energetic boy from throwing stones at something or somebody, and the majority of boys' games are based on throwing, batting, kicking, shooting, or otherwise projecting balls, marbles, &c. &c. The more energetic the race, the more they seem addicted to projectiles of some sort, and aiming at something. The typical American when deprived of opportunity for using his six-shooter, and is otherwise reposing, asserts his humanity by spitting at any surrounding objects that may be conveniently used as targets; and although bows and arrows have long since become useless, archery still continues a popular recreation. Portable tubular shooting galleries, "aunt Sallys," "three throws a penny," &c. &c., are prominent elements of amusement at all fairs, wakes, race-courses, and other holiday assemblages.

The invention of the returning boomerang was probably accidental. A stick-throwing savage would soon discover that a flattened stick skims the air and flies farther than a round one, and would shape his missiles accordingly. One of these, an elbow-shaped branch of a tree, having accidentally the requisite curvature, would return, and consequently become a valued treasure at first, and afterwards an object of imitation. Nobody can suppose that the boomerang was discovered by any process of thought or instinctive preconception of its properties. It would be interesting to observe whether in those districts to which the boomerang appears indigenous, there is any tree that grows naturally with branches having the required curvature.

The sling was doubtless a result of mechanical reasoning, or rather of intuitive mechanical perception of the laws of motion. The invention and construction of the bow, even of such bows as are used by the rudest savages, demand a considerable effort of mechanical ingenuity.

Here the elasticity of a solid is used as a means of storing, accumulating, and concentrating muscular power in such a manner, that the whole force of a somewhat protracted muscular effort is converted into an instantaneous projectile impulse, with scarcely any loss from friction or other mechanical disadvantage.

Although we have superseded all the forms of long bow, cross bow, catapult, &c., we still urge all our modern and most improved projectiles by the same

force as that which sped the bolts and arrows of our savage ancestors. Our bombs, and shot, and bullets, are projected by elastic energy, but instead of using the elastic reaction of a strained solid, we now avail ourselves of the expansive elasticity of gases. In the air-gun, gaseous elasticity is used in strict analogy with the elasticity of the bow. The air is condensed by the muscular effort of pumping it into the stock or other receptacle, and the muscular energy is thus accumulated and stored in this condensed air as in the bent bow. The trigger releases a portion of this compressed air, which by its expansive reaction projects the ball just as the reaction of the suddenly relaxed bow propels the arrow.

The great amount of friction to be overcome in pumping, and the loss of power due to windage, renders the air-gun a wasteful machine for the concentration and transmission of muscular power. It is therefore inferior to either the long or cross bow, and has not been used in practical warfare, although its invention is attributed to Ctesbius, who lived in Alexandria 120 B.C.

Instead of using muscular power to bend the elastic solid or condense the elastic gas, we now exert the power of knowledge, and summon, by the incantations of science, the subtle powers of chemical affinity to work in our service, by holding imprisoned gases in solid or liquid bondage, until we permit them to burst freely forth and do our bidding by the explosive violence of their sudden expansion.

This explosion, or the sudden conversion of a solid or liquid into gas, is effected either by the application of heat, of electricity, or simple percussion. The simplest instances are presented by some of the compounds of nitrogen, such as the chloride of nitrogen, the iodide of nitrogen, the fulminates, &c. Chloride of nitrogen, for example, is composed of two elements, both of which under ordinary circumstances are gaseous, and which are held together in liquid form by such very weak affinities, that the slightest vibration is sufficient to sever them. Thus the touch of a feather may explode this most dangerous compound, the explosion being simply the resolution of the oily liquid into its component gases, nitrogen and chlorine.

In the case of the fulminates, the action is similar, but rather more complex; the vibratory shock resolves a highly complex solid compound into gaseous compounds of less complexity.

The explosion of gunpowder, guncotton, nitro-glycerine, &c., is effected by an essentially different chemical action. Here we have a solid or liquid compound rich in oxygen, associated with combustible substances which form gaseous compounds when united with oxygen. The oxygen compound is dissociated or decomposed, and wholly or partially converted into gaseous matter, exerting primarily its own explosive force thereby, and by the combination of its free or nascent oxygen with the combustible solids, a further development of gases, and a secondary explosive force is added to the first.

English school-books tell us that Roger Bacon, who

died in 1278, was the inventor of gunpowder, and German authorities of the same class attribute its invention to Berthold Schwartz, who lived at Mayence between the time of Roger Bacon's death and 1320; but it is probable that both of these and also Albertus Magnus obtained their recipes from the 'Liber Ignium ad Comburendos Hostes' of Marcus Græcus, who probably obtained his information from the Greeks of the lower Empire, whose "Greek fire" appears to have been a copy of the rudely made blasting and firework powder that had been used during more than a thousand years previously in China and India, the secret of which was probably carried to the Greeks by the Arabs who traded with the farther East. To all these historical probabilities may be added another, viz. that the Oriental powder was merely a deflagrating composition, like that at present used for squibs and rockets; such as an amateur of the present day would produce, were he simply to mix common charcoal with ordinary commercial sulphur and saltpetre in the proportions given in a mere recipe of quantities used for making gunpowder. It seems likely that the primitive Oriental powder was merely used for blasting and fireworks, with occasional displays of fire and smoke during warfare, for the purpose of frightening rather than otherwise injuring the enemy.

The perfecting of the manufacture of gunpowder, sufficiently to render it practically applicable to the purposes of destructive warfare, is undoubtedly due to the dawning chemistry of the European alchemists and their immediate successors.

Gunpowder is composed of nitre, charcoal, and sulphur. Its theoretical composition is :—

		Per cent.
1 equivalent nitric acid 1 equivalent potash	nitre	74·8
1 equivalent sulphur		13·3
3 equivalents carbon		11·9
		100·0

The proportions practically used have been determined by the examination of practical results irrespective of theoretical considerations, but they approximate very closely to the above figures, thus :—

	Nitre.	Charcoal.	Sulphur.
English gunpowder contains ..	75	15	10
French ditto (military)	75	12·5	12·5
Ditto ditto (sporting)	76·9	13·5	9·6
United States ditto	75	12·5	12·5
Prussian ditto	75	13·5	11·5
Chinese ditto	75·7	14·4	9·9
French blasting powder	62	18	20
English ditto	65	15	20

Blasting powder varies considerably in composition. It will be seen from the above that it contains a much larger proportion of sulphur than gunpowder, nearly equal to two equivalents. This increases the intensity and rapidity of its explosion, and the smaller proportion of nitre lowers its cost. It is usually made up into large angular grains from the size of mustard seeds to small peas, but not very uniform either in size or shape, and is less carefully prepared than good gunpowder. The excess of sulphur renders it unfit for

firearms, owing to the free sulphurous acid generated by its combustion. This would rapidly corrode the barrels.

Purity of the ingredients is of primary importance in the manufacture of gunpowder. Saltpetre as imported contains many impurities, such as common salt, sulphate of potash, and nitrates of lime and magnesia. These render the nitre unfit for gunpowder making, chiefly on account of their absorption of moisture from the air. They must therefore be removed, and pure nitrate of potash obtained. Water at 60° dissolves only one-fourth of its weight of pure nitrate of potash, but when raised to the boiling point, water dissolves nearly two and a half times its own weight, or about ten times as much. Common salt is nearly equally soluble in hot and cold water, while sulphate of potash is less soluble in boiling water than the nitrate in cold. The nitrates of lime and magnesia are both deliquescent, and besides this are addicted to the formation of a coagulable mixture or compound, when dissolved in company with gelatine.

The purification of nitre is effected by taking advantage of these properties. The English method is to add the crude nitre to a small quantity of water, and raise this to the boiling point. The nitrate of potash is thus all dissolved, while the greater part of the chloride of sodium and sulphate of potash remains undissolved, and are thus separable in a solid state from the hot solution. Then this solution is allowed to cool. About nine-tenths of the nitrate of potash that was soluble in the boiling water now becomes

insoluble, and is therefore precipitated as solid crystals, while the deliquescent nitrates of lime and magnesia and the unremoved chloride of sodium remain dissolved in the mother liquor. By means of two or three successive crystallizations, the nitrate of potash is thus obtained in a state of approximate purity. It is then freed from water by fusion.

The French method, now more generally adopted, is to dissolve crude nitre in the smallest possible quantity of water, heated in a large copper boiler. Such a solution may be raised considerably above 212°, and thus a quantity of crude nitre equal to five times the weight of the water may be gradually added and all its nitrate of potash dissolved. A large proportion of the chloride of sodium and sulphate of potash remain undissolved. The crystals of these are removed by means of perforated ladles, and the solution is then diluted, glue dissolved in hot water being added and well stirred into it; the coagulum which forms as a scum on the surface is removed, the liquid is cleared by boiling, and then cooled to 195° and transferred to a shallow vessel with a V-shaped bottom, where it is kept in agitation while cooling. Small crystals of nitrate of potash are thus formed and settle at the bottom, while the chloride of sodium, being nearly as soluble in cold as in hot water, remains in solution.

The crystals of nitrate are then removed to tanks with perforated false bottoms, and a cold saturated solution of saltpetre is poured upon them, which completely dissolves and washes away the remaining chlorides, sulphates, &c., but leaves the pure nitrate of

potash undissolved. The crystals are further washed with pure cold water and then dried. The small portion of nitrate of potash dissolved away in these wash waters is of course economized, by using it as the solvent or washing solution in the previous processes.

The sulphur is purified by redistillation. This distilled sulphur is ground to a fine powder or meal.

The charcoal is prepared from alder, dog-wood, or willow, by carefully heating the wood in iron pots or retorts. Alder is preferred for best gunpowder. Poplar and other white woods are used for blasting powder.

Each of these materials is carefully ground to fine powder and sifted, then thoroughly mixed by means of a revolving drum. By Act of Parliament the charge for a mixing machine is limited to 50 lb. for best powder, or 60 lb. for inferior kinds.

This mixture is next made into a paste with water and transferred to the *incorporating mill*, where it is placed in a circular trough, over and around which two heavy rollers set on edge are running. The bed and rollers were formerly made of marble, on the supposition that this is safer than metal, but it was found that mills with cast-iron beds and cast-iron rollers explode no more frequently than those of marble. The charge of these mills is limited to 50 lb. for each trough. They are usually built in sets of four or six, all superintended by one man, whose chief duty is to maintain the moisture of the mixture during the grinding, which is continued for several hours. As the danger of explosion is considerable, these mills are isolated by strong walls, and at the Government works

at Waltham Abbey a water tank is suspended over each mill in such a manner, that an explosion of any one mill overturns its own tank and all the others of the set, and floods all the charges.

The ground paste thus obtained is now broken into thin powder in the *breaking-down house* by means of rollers. This is a dangerous operation, mainly on account of the fine dust which is diffused through the air, and settles on every ledge and projection of the building. By lining the building with glazed material, the friction, and consequent danger of brushing away this dust is diminished, and the danger is further lessened by only permitting the workman in charge to enter for renewing and withdrawal of the charge after the machinery has stopped. He retires in the meantime to an adjoining bomb-proof chamber, from which he can set the machinery in motion or stop it when required.

The powdered cake now passes to the *press house*, where it is placed in layers in metallic boxes or cylinders lined with wood, in which it is subjected to a pressure of about 120 tons to the square foot by means of hydraulic machinery. This reduces it to about half the thickness of the original powder, and converts it into solid slabs of stony hardness. The "*press cake*," thus prepared, is next subjected to the process of "*corning*," or "granulating," by breaking up and passing it through sieves of varying fineness. As this is a dangerous part of the manufacture, 12 cwt. is the maximum quantity allowed to be corned at one time, and not more than double that quantity may be *in the* corning house at one time. The fine dust dif-

fused through the air, and which settles upon every part of the house, is the chief source of danger; as when dry it is easily inflammable, and from its general distribution the firing of any portion would be communicated throughout the building.

The next process is drying. Fifty cwt. is allowed in the drying house, as this process is far less dangerous than the preceding. It is usually effected by passing a current of dry air, heated by steam pipes, over the granulated powder, which is spread out on shelves in the drying house.

It is next taken to the *dusting house*, where it is freed from dust, and the grains are polished or glazed by agitating them together in revolving cylinders with wire gauze sides. The dust passes through the meshes of the gauze, and the grains rub off each other's angles, and thus become rounded and smooth.

The pressing and glazing make the gunpowder less permeable to moisture, and better able to bear carriage and friction, besides which, its uniform density and equal size of grain render its quantity easily measurable. A fictitious glaze is sometimes imparted by means of plumbago.

In order to prevent accidents, nothing made of iron is allowed in any portion of the works, excepting the incorporating mills; the floors of all parts, excepting this, are covered with leather, fastened down by copper nails. No one may enter with ordinary boots or shoes, only slippers or "magazine shoes" being allowed. The growth of grass around each building is encouraged, to diminish the risk of admis-

sion of grit. Where practicable, it is desirable to surround the buildings with a small moat, crossed by wooden platforms kept wet. The prohibition of smoking is, of course, enforced, though not without some difficulty, as even in gunpowder works, men who have acquired a mania for tobacco are mad enough to carry lucifer matches and indulge the propensity, if not strictly searched and watched. So great is this difficulty that, in his report to the Government, Professor Miller says, "Change of clothes should be enforced by legislation. It is the only method of preventing the surreptitious introduction of lucifer matches into the works, which men in the habit of smoking cannot be induced to forego."

The object of the corning or granulation of gunpowder is to leave a space between each grain, and thus allow the flash from that which is first fired to permeate the whole, and envelope each of the other grains in an atmosphere of flame. Otherwise the explosion would take place by successive communication from one particle to another, after the manner of a fuse. This may easily be shown by wetting a little gunpowder, breaking up the granules, redrying, and firing it.

Count Rumford found the specific gravity of British Government powder to be as follows:—

As it lies in a heap mixed with air	0·836
Well shaken together	0·937
The solid substance of the powder	1·745*

* It is now made rather more dense, 1·79 to 1·80.

This shows, that the interstices between the grains are nearly equal to the spaces which the grains themselves occupy. He found that brass dust, or any other finely-powdered solid, mixed with a given quantity of gunpowder materially diminished its projectile power. On the other hand, subsequent experiments have shown that the admixture of a little sawdust rather increases the effect of blasting powder. The contradiction, however, is only apparent, as all the solids that Rumford used were so finely divided that they simply filled the interstices between the grains, while the sawdust is itself granular, and large enough to separate the grains farther from each other.

The explosion of gunpowder depends upon the fact that the elements of nitre are dissociated by heat, gaseous oxygen being set free. The nascent oxygen combines with the carbon and forms carbonic oxide, or carbonic acid, also gaseous. When the sulphur is in excess, as in blasting powder, there is a further formation of gaseous sulphurous acid, but in gunpowder the sulphur should unite with the potash, and form solid sulphide of potassium. When this reaction is complete, little or no corrosion occurs, but such complete combination of the sulphur with the potassium is theoretical rather than a practical fact, more or less of sulphurous acid being usually formed.

The nitrogen and carbonic acid gases (excluding sulphurous acid) formed by the explosion of a given bulk of gunpowder of ordinary density, occupy about 300 times the bulk of the powder at ordinary temperatures, and the heat of combustion expands these gases

still further.* To this expansion, as already stated, the explosive force is due.

A cubic foot of good English cannon powder should weigh 58 lb. Two ounces of such powder will throw a 68-lb. shot from a mortar set at an angle of 45° to a distance of 260 to 280 feet. By comparing this result with the weight of material used, we arrive at some idea of the tremendous energy which is potentially stored in so small a quantity of solid.

Count Rumford made a great number of ingeniously devised experiments, in order to determine the expansive or projectile force of fired gunpowder. Mr. Robins had previously estimated it at 1000 atmospheres, or 15,000 lb. on the square inch; and Bernouilli at ten times as much. Rumford exploded small quantities of powder, 10 to 20 grains, in a thick iron cylinder with a $\frac{1}{4}$-inch bore, entirely closed at one end, the open end carefully plugged, and with a cannon weighing 8081 lb. resting on the plug. By the lifting of this weight and the bursting of the cylinder, he endeavoured to measure the explosive force. One of his most remarkable experiments was with a barrel or cylinder $2\frac{3}{4}$ inches long, $2\frac{1}{4}$ inches diameter, with a bore $\frac{1}{4}$ inch diameter, and 2·15 inches long, the metal thus being $1\frac{1}{4}$ inch thick all round the bore, or five times its diameter. On charging this with $\frac{1}{10}$th of a cubic inch, or 24 grains of powder, and firing it by means of a red-hot ball ap-

* Dr. Miller estimates this expansion at 1500 times the bulk of the powder. This is far too low to explain its expansive force.

plied to the closed end of the cylinder, it "burst the barrel asunder in which it was confined, notwithstanding its enormous strength, and with such a loud report as to alarm the whole neighbourhood." He further states that "it is impossible to describe the surprise of those who were spectators of this phenomenon. They literally turned pale with affright and astonishment, and it was some time before they could recover themselves."

By testing the tenacity of the iron used, i. e. the force required to tear asunder a piece of given sectional area, he calculated the explosive force of the powder to amount to 54,750 atmospheres, or 621,250 lb. = 277 tons per square inch. Recent experiments made by the "Committee on Explosives" appointed by the British Government afford very different results, viz.:—

	Tons.		
R. L. G. service powder	20·8	maximum pressure	per sq. in.
Russian prismatic ..	20·5	"	"
Service pellet	17·4	"	"
Pebble, No. 5	15·4	"	" *

These results were obtained by using the "crusher gauge," a cylinder of copper half an inch long and rather more than a quarter of an inch in diameter,

* In some recent trials of the eighty-one-ton gun at the Royal Arsenal, the crusher gauge indicated a pressure varying from 27·7 to 28·1 tons, with charges of 220 to 250 lb. of powder. In comparing these results with Rumford's, we must not forget that in the Woolwich experiments the expansive force of the liberated gases was acting within an expanding chamber, one of its walls being the movable projectile.

which is crushed by a piston that communicates to it the expansive pressure of the explosion. The amount of compression of the copper measures the force.

This enormous discrepancy—the difference between 20 tons and 277 tons—indicates serious error somewhere, either on the part of Rumford or the committee, or both. It appears to me that both results are erroneous, and for the following reasons.

Rumford tested the tenacity of the iron by the breaking weight of a gradually applied and continuous strain, but the fracture of his barrel was produced by a sudden vibratory shock. Now the force required to break iron or steel is much smaller in the latter than in the former case. I have made several experiments on this subject, and find that this difference is greater for steel than for iron, and increases with the hardness of either; that carbon, while it increases the tenacity of iron as tested by a gradually applied strain, diminishes its power of resisting vibratory shocks; that phosphorus acts in like manner, but even more decidedly than carbon. This was proved by tearing asunder pieces of the same iron, first by the gradual and measured strain of a hydraulic press, and secondly by a given weight falling from given heights. The tenacity according to the first test increased, according to the second diminished, with the increase (within certain limits) of carbon or phosphorus. Rumford's test of tenacity corresponded with the first, while the gunpowder fracture resembled the second, and, if he used a hard steely iron, the difference would be very great.

His other very numerous and well-conducted experi-

ments, in which the initial explosive force was measured by the lifting of a weight, indicated a maximum initial force of 10,977 atmospheres, or 73 tons per square inch, with 18 grains of powder.

In all these experiments the weight pressed upon an effective plug in such a manner, that no escape of the products of explosion could occur without lifting the weight. When such lifting occurred, an explosion was heard and the escape of gas was made visible. When the force was insufficient to lift the weight, only a slight, barely audible sound was produced, like that of cracking a piece of glass.

For Rumford's purpose—viz. that of measuring the momentary initial expansive power—these experiments, made in 1793, and fully described in Rumford's essays, published in London, 1802, appear to me far more satisfactory than those of our official committee with the "Rodman" and "Crusher" gauges reported in 1870, for the following reasons.

1. The resistance to be overcome, and by which the force was measured, viz. the gravitation of a known weight, was far more definite and measurable than the degree of indentation or compression of a cylinder of copper, which serves as the measure of force in the Rodman and Crusher gauges.

2. In Rumford's arrangement, the force of explosion was more directly applied to the resistance by which it was measured than in the official experiments, where the shock of the explosion was first communicated to a solid piston 1 inch in length, and by this transferred to the copper cylinder of the crusher gauge, or the

knife of the Rodman gauge. By this arrangement much of the force is expended upon internal work in the intervening piston producing mechanical vibration of its substance, and a returning wave of elastic compression, which would have no measurable effect on the gauge. Besides this, another portion of the force compressing the piston must be converted from mechanical motion into heat motion.

If any reader supposes that I am hypercritical in making this objection, let him try the following experiment: Take a block of iron—a common 1 lb. weight for example—place it on the hand, and the hand upon a table; then strike the weight smartly with a carpenter's hammer. It will be found that blows which would fearfully mutilate the hand if directly applied to it, may be struck upon the weight thus resting entirely upon the hand, and will scarcely be felt, provided the blows are dealt suddenly and smartly. The mountebank's exploit of breaking a great stone on a man's bare breast, the common method of reducing the dimensions of geological specimens by holding them in the hand and cracking with a hammer, and the experiment of shooting a bullet through a swinging door without moving it on its hinges, are familiar illustrations of this principle, which appears to have been overlooked in these official researches.

The complete absence of windage in Rumford's arrangement by exploding in a perfectly closed chamber is a third advantage.

I therefore regard Rumford's experiments as the best that have yet been made on this interesting

subject, although, as he himself admits, they are by no means free from error.

In the eighty-fourth experiment with 84 grains of powder exerting an uplifting force of 10,977 atmospheres, the barrel was not filled, but contained only 0·702 parts of its total capacity. According to Rumford's formula, based on the general result of all his experiments, the force should be 39,346 atmospheres, had the barrel been completely filled and the whole of the powder exploded. This is much below the 5475 atmospheres calculated upon the basis of the tenacity of the iron, but not greater than the probable difference due to the fallacy, which I have pointed out.

It must be noted, that in these experiments the conditions are not the same as in the explosion of gunpowder in firearms. By Rumford's method the whole of the powder was exploded almost instantaneously, and all its explosive force expended in lifting the weight.

In reference to this subject, Rumford fairly asks, "How does it happen that firearms and artillery of all kinds, which certainly are not calculated to withstand so enormous a force, are not always burst when they are used?" He answered this question by an investigation of the well-known fact, that when cannons, mortars, or muskets, such as used in his time, were discharged, a considerable quantity of unconsumed powder was always blown out of them, not only from the muzzle, but even from the touch-hole, *where the fire enters to inflame the charge.*

He inferred that it is improbable or impossible that such grains, actually in the chamber of the piece, and

completely surrounded by flame, should by the action of that very flame be blown out of it without being at the same time set on fire, and supposed that they must be first fired, and then extinguished by the velocity of their projection into a cold atmosphere. If such be the case, each grain must occupy some time in burning from its circumference to its centre, and this time must increase with the size of the grains.

To test this, he procured powder made up of a mixture of grains varying in size from the finest "Battel" powder to grains "nearly as big as large peas," but all of the same composition and density. He placed a number of vertical screens of very thin paper one behind another at a distance of 12 inches apart, and fired charges of this mixed powder from a common musket (sometimes with, sometimes without a wad) against the foremost screen. The papers were renewed for each experiment, and the distance of the muzzle of the gun was 8, 10, or 12 feet from the first screen.

The large grains struck the screen, sometimes passed through all the five screens, and were collected unconsumed, although evidently burned outside. The most decisive experiments were made with a single large grain, propelled by varying charges of fine-grained powder. This never failed to reach the first screen, sometimes whole, at others broken; in some cases it passed through all the screens. When propelled with small charges, these grains set fire to one or more of the screens; when with large charges, they passed through the foremost screens without setting them on fire, but

did set fire to one or more of the hindmost, and then struck a board placed 12 inches behind the last screen.

By dropping a piece of red-hot iron into the barrel of a horse-pistol, and then dropping upon this a grain of coarse powder, it was projected by its own explosion, and seen burning in the air by the train of light left behind it, like a falling star.

It was thus rendered evident that the rapidity of the explosion of gunpowder must vary with the size of the grains, when other conditions are equal.

This principle is now applied practically in artillery. A considerable force is necessary to start the motion of a heavy mass like a cannon ball, and it is evident that if the whole explosive force of the charge of a cannon were expended instantaneously, a violent bursting strain must be exerted against the sides of the gun before the forward motion of the ball is fairly effected, while on the other hand if the explosive force of the powder can be gradually applied in such a manner, that it shall be continually augmented during the time occupied by the ball in passing through the bore of the gun, an accelerated motion of the ball will be effected with a minimum strain upon the piece. This may be attained by using gunpowder of large grain, the theoretical condition being obviously, that each grain shall occupy the same time in exploding that the ball requires for travelling to the gun's mouth. If this is carried out, the whole force will be expended in propelling the ball in the most advantageous manner and with a minimum bursting strain upon the gun. If the grains are so large that they occupy more time

in exploding, than is expended by the ball in reaching the cannon's mouth, a portion of their explosion will occur after the ball has left the gun and consequently be wasted.

In the Preliminary Report of the Ordnance "Committee on Explosives," published Feb. 1870, the use of "pebble" powder for heavy guns "to be produced by breaking up 'press cake' of the specified density (1·80) into lumps which are retained between sieves of $\frac{5}{8}$ and $\frac{4}{8}$ mesh," is recommended, as "its use will materially reduce the initial strain exerted by the exploding charge, thereby prolonging the life of the gun and diminishing the risk of accident."

The Russian "prismatic" gunpowder has been adopted for the same object with unquestionable success, which must depend upon the principle which I have above enunciated. The size of the prism pebble, or pellet should therefore *be proportionate to the length of gun, and the time required by the ball in travelling to the muzzle*, due allowance being made for the effect of pressure upon the rapidity of combustion.

In the recent experiments with the eighty-one-ton gun at Woolwich, the powder was made into cubic grains $1\frac{1}{2}$ inch diameter.

This subject of the ratio of the size of powder grain to the length of the gun, and also that of the influence of pressure on the rapidity of the combustion of large powder grains, are, I think, worthy of exhaustive experimental investigation in the Royal Arsenal. If they were understood, large guns might be constructed and charged more scientifically than at present, and

fewer destructive experiments *after their construction* would be needed. Besides this, the maximum of economy in powder might be attained, as the conditions of such economy would be predeterminable by calculation.*

White gunpowder is a mixture of 2 parts of chlorate of potash, 1 of loaf sugar, and 1 of prussiate of potash. These are separately reduced to powder, and mixed dry with the smallest possible amount of friction. It has little or no practical value, although its explosive power is very great. Its liability to explode by friction is so great that it cannot be granulated safely, and in its powdered state will not bear the ordinary shocks and friction of carriage. If used at all, the powdered materials should be carried separately and mixed on the spot, only in such quantities as are required for immediate use. A mixture of chlorate of potash and sulphur has similar properties and requires similar precautions. The energy and dangerous nature of this mixture is easily shown by taking one or two grains of chlorate of potash and about an equal quantity of powdered sulphur and rubbing them together with a heavy pestle in a strong mortar. A violent explosion is the result.

A mixture of chlorate of potash, sulphide of antimony, and powdered glass, "*Friction tube priming*," is the charge for friction tubes used in firing cannon, and has similar properties to the above. The powdered

* Since the above was written I have been informed that further experiments bearing on this subject have been made, and that an official account of them will be published.

glass is purposely introduced to render the friction more effective; its function is purely mechanical, the explosion depending upon the other two ingredients.

Picrate of Potash is a yellow crystalline salt, made by adding, drop by drop, six parts of strong nitric acid to one of carbolic acid. It explodes when heated, and forms still more explosive mixtures with chlorate and nitrate of potash, either with or without charcoal. These must be mixed dry, and are liable to explosion by friction.

All these mixtures resemble gunpowder, in containing a combustible substance or substances mixed with a compound which yields oxygen by dissociation. The oxygen of chlorate of potash is more readily dissociated than that of nitre, and hence the more dangerous and powerful character of the mixtures containing it.

Guncotton is prepared from ordinary cotton or cotton waste. This is first boiled in carbonate of soda to remove greasy and resinous matter. The soda solution is removed by means of an ordinary centrifugal drying apparatus; the cotton is then washed in pure water and again dried, after which small charges of from 1 lb. to 2 lb. are treated with a mixture of one part nitric acid to three parts sulphuric acid, both concentrated.

As considerable heat is evolved when these acids are mixed, they must be set aside to cool before use. One pound of cleansed cotton is then carefully and gradually immersed in 15 lb. of the mixed acids, kept cool by water surrounding the vessels containing the

acid. The cotton is left in the acid for about forty-eight hours, then partially dried from the acid by a centrifugal apparatus, afterwards thoroughly washed in pure water and a little carbonate of soda until no traces of acid remain, and finally dried by steam heat in a detached building, as this latter is the only dangerous stage of the manufacture.

When thus prepared, guncotton is not distinguishable in appearance from the ordinary cleansed cotton from which it is made; but when required for firearms or blasting, it is now usually prepared in a compressed form, by passing it, before drying, through a pulping machine, such as is used in the manufacture of paper, then compressing it in cylinders into the form of discs of convenient size. The pressure employed is sometimes as much as 6 tons to the square inch. These discs on leaving the press retain fully 20 per cent. of water, and in this state will not explode, nor even burn, when touched with a red-hot poker. Guncotton may be preserved in this damp state for years, and will bear long immersion in water without damage. It only requires drying, and is then fit for use. This is one of the most important advantages of this explosive.

It is not, like gunpowder, merely a mechanical mixture of combustible with oxygen-giving materials, but is a true chemical compound, in which peroxide of nitrogen (derived from the nitric acid) replaces or substitutes a part of the hydrogen of the cotton fibre without destroying its structure. The dissociation of this peroxide of hydrogen supplies the oxygen required

for the combustion of the carbon and the remaining hydrogen of the cotton fibre. The products of this combustion are simply carbonic oxide or carbonic acid and water; there is no sulphurous acid, nor other sulphur compounds such as are produced by the combustion of gunpowder, as the sulphuric acid used in the manufacture of guncotton forms no remaining compound, but simply aids the combination of the peroxide of nitrogen with the fibre.

Guncotton takes fire at about 300° Fahr. (gunpowder at 600°). In the open air it burns furiously with a brilliant flame and without explosion. Its combustion in this case, though rapid, is gradual, and with very little mechanical effect. This may be shown by placing a piece of loose guncotton about the size of a walnut upon the palm of the hand, and firing it by a match. No inconvenience is suffered, as the combustion is too rapid for the heat of the flame to be conducted through the cuticle to the sensitive skin below, and not sufficiently sudden to hurt the hand by its explosive force.

If suddenly kindled by means of a detonating fuse, it explodes violently, and exerts a mechanical force which has been estimated at three to six times greater than that of an equal weight of gunpowder. If a piece of dry guncotton be struck smartly with a hammer on an anvil it will explode, but the explosion is limited to the portion actually between the hammer and anvil.

Boxes of guncotton placed at a distance of 100

yards have been fired at by a rifle; in many cases the blow of the bullet has inflamed the guncotton, which has rapidly burned away, but without explosion.

A 28-lb. case of compressed guncotton was inflamed by means of an electric fuse, which was passed through the side of the box; "there was no explosion; a dull puff and a large volume of bright flame were observed." *

"A 28-lb. service case of compressed guncotton fitted with an electric fuse, as in the first experiment, was placed on the ground closely surrounded on all sides by seven similar cases all packed in the same manner. Two cases filled with damp guncotton (which had been stored in that condition at Woolwich for about five years) were placed upon the boxes containing the dry guncotton, and the pile was then surrounded by thirty-two other cases, each containing 28 lb. of earth, which were stacked upon and around them. The ignition of the electric fuse was immediately followed by a large body of flame, which penetrated through all the pile, and directly afterwards a second similar volume of flame was observed, but there was no approach to an explosion." †

On examining the heap after firing, it was found that only one side was disturbed, and that only one box in addition to that fired by the fuse was ignited. Other

* Minutes of Evidence relating to Explosion of Guncotton at Stowmarket, No. 13 (Colonel Younghusband).

† Ibid., No. 14.

boxes were charred and burning externally, but were easily extinguished without any explosion, or even burning of the guncotton they contained.

There can be no doubt that the manufacture and storage of guncotton is far less dangerous than that of gunpowder, though the explosion at Stowmarket, &c., shows, that when the capacities of a guncotton factory are overstrained, when too much is done in a given space and by a given number of men; when there is much hurrying to complete a large contract, and too much reliance is placed upon the supposed safety of this explosive, the results may, as at Stowmarket, be very tragical. Imperfect washing from acid is one source of danger.

Guncotton is chiefly useful for blasting purposes, for torpedoes, and other explosive uses where a detonating fuse is available as the means of ignition. The absence of sulphur would render it especially suitable for ordinary firearms, but the risk of detonation in ramming the charge is a serious objection. Guncotton may be prepared in the form of yarn, in skeins, rope, loose fibre, or compressed discs and cartridges. It was discovered by M. Schonbein, a Swiss chemist, in 1845.

Schultz's Gunpowder is made from wood, which is first sawn into sheets about $\frac{1}{16}$th of an inch in thickness, and then reduced to grains of uniform size by means of a punching machine. The resinous and albuminous matters of the wood are removed by boiling for some hours in carbonate of soda; the grains are then further

washed in water, steamed and bleached by chloride of lime, washed again, and dried. The granulated wood is thus brought to nearly the same composition as cotton fibre, i. e. pure lignin or woody fibre, composed of carbon and the elements of water. It is now treated with the mixture of nitric and sulphuric acids as in the production of guncotton, and similarly washed and dried. The final drying is the only dangerous part of this manufacture.

Twenty-six parts of nitre, or $22\frac{1}{2}$ nitre, and $7\frac{1}{2}$ of nitrate of baryta are now dissolved in 220 parts of water, and the prepared wood granules are placed in this solution, saturated with it and then dried. This completes the process, whereby an explosive of intermediate nature between gunpowder and guncotton is produced, but free from sulphur and the corrosive products of its combustion.

Nitro-Glycerine was discovered in 1847 by Sobrero, an Italian chemist. It has also borne the name of *glonoin* and *blasting* oil.

The well-known intensely sweet viscous liquid called glycerine, which is separated from oils and fats in the course of candle making, although so different in appearance from cotton fibre and other forms of lignin, is very similar in chemical composition, and when acted upon by a mixture of nitric and sulphuric acids, undergoes a chemical change corresponding to that effected by the same means upon the cotton fibre. Some of its hydrogen is removed, and peroxide of nitrogen takes its place. As in guncotton, the disso-

ciation of this supplies the oxygen necessary for the combustion of the remaining carbon.

Nitro-glycerine thus produced is a colourless or yellowish oil, of specific gravity 1·620. It therefore sinks in water, in which it is not soluble. It is readily soluble in spirits of wine, wood naphtha, and ether. Like ordinary fixed oils, it does not evaporate to any appreciable extent at ordinary temperatures, but at 212° is gradually decomposed and dissipated. It has a pungent, sweetish, and rather aromatic taste, and is poisonous. It freezes into a crystalline solid at low temperatures, and this solid liquefies at 43° or 44° Fahr. Like water, it expands in freezing, and may thus burst the vessels containing it. It should be thawed by placing the vessel containing it in warm water, the direct application of dry heat being dangerous. At Hirschberg a mining overseer was killed by the explosion of some frozen nitro-glycerine which he attempted to break with a pickaxe. In this state it is more liable to explosion by simple percussion, than when liquid.

Nitro-glycerine, *when pure*, behaves nearly the same as guncotton as regards its combustion and explosion. It takes fire and burns with a smoky flame without explosion, when a lighted match is applied to it. If gradually heated upon a plate of metal, it slowly evaporates and generally takes fire, burning rapidly but not exploding, but if rapidly heated to about 360 Fahr. it explodes violently.

If a little of the liquid be placed on an anvil and smartly struck with a hammer, the portion under the

hammer explodes, but as in the case of guncotton, the explosion does not extend to the liquid beyond the hammer. If an open vessel containing nitro-glycerine be thrown into a fire, the liquid usually blazes without explosion; but this is not to be relied upon, as explosions have occurred under such circumstances.

Many serious accidents have occurred in the transport of nitro-glycerine, and even in stores where it has been subject to no mechanical violence. These appear to have arisen from some kind of spontaneous decomposition which is not at present understood. The liability of this liquid to decompose renders it much more dangerous than the more stable, solid guncotton. Mr. Abel's experiments show, that it is especially liable to dangerous decomposition when raised to any temperature above 90° Fahr. This temperature may be attained by exposure to the sun's rays. When made from impure glycerine, or retaining any traces of acid, it is much more liable to decomposition, and is then dangerous at any temperature.

The ordinary mode of using it for blasting purposes is, to pour the nitro-glycerine into a hole drilled in the rock, then fill up the hole with water and introduce a waterproof fuse, to which a small charge of fulminating mercury is attached. The detonation of this causes an immediate and certain explosion of the liquid nitro-glycerine. In the frozen state it may be fired by the same means, but not with equal certainty.

Its explosive force is estimated at five to ten times that of an equal weight of gunpowder. This, and the facility with which it may be used, renders it a most

valuable blasting agent; the danger of storage and handling alone prevents its more extensive application to this purpose. Various methods have been devised for diminishing this danger, such as dissolving it in wood naphtha, alcohol, &c., but these have failed on account of the volatility of the solvent and the unchecked liability to decomposition of liquid nitroglycerine.

Mixtures of nitro-glycerine with solid absorbent substances have been more successful. Mr. Horsley uses four times its weight of alum, and thus obtains a solid that is not explosive by the action of a simple flame, but which may be detonated by a percussion fuse.

The *Dynamite* of M. Nobel is similar to this, being a mineral known in Germany as Kieslgühr, saturated with liquid nitro-glycerine, of which it is capable of absorbing about three times its own weight. This mineral is an aggregation of the excessively minute and delicate silicious sheaths of microscopic vegetable organisms which, though separately invisible to the naked eye, occur in such prodigious numbers that they form considerable deposits in Oberlohe (Hanover) and other localities.

The solid dynamite thus prepared, and containing 70 to 75 per cent. of the blasting oil, is a pale reddish-brown powder, which burns quietly when thrown into fire, but may be exploded as readily as pure nitroglycerine by means of a detonating fuse. Its explosive force is proportional to the quantity of the blasting oil which it contains. It will bear considerable concussion without explosion. This is usually attributed to the

elasticity of the solid silicious particles and the consequent moderation of the shock. A weight of 56 lb. falling from a height of 6 or 7 feet upon a naked dynamite cartridge will not explode it, and when dynamite is packed in a wooden box, it will bear without explosion the shock of the fall of 100 lb. from double that height.

The *Lithofracteur* of M. Krebs, composed of 52½ per cent. nitro-glycerine, 22½ per cent. silica, 25 per cent. "mineral bodies" (finely divided carbon sulphur, nitrate of soda, silica, clay, sand, and wood fragments) is a modification of dynamite, with similar properties; but from the experiments made by the special committee on guncotton, &c., it appears to be rather more dangerous on account of its greater liability to permit the exudation of small quantities of liquid nitro-glycerine. The committee report that they "are of opinion that the substance provided for their experiments under the name of lithofracteur has imperfectly fulfilled the absolutely necessary property of retaining its proportion of nitro-glycerine under circumstances which might be met with during ordinary transport or storage."

It was found, when lithofracteur cartridges were exposed to considerable variations of temperature, such as freezing and thawing, that the paper envelope was moistened with nitro-glycerine, and that a drop thus absorbed on paper exploded on being struck with a hammer.

Cartridges of dynamite were similarly frozen and then warmed without any appearance of exudation.

Mr. Chas. L. Kalmbach, in an article published in Van Nostrand's Magazine, states, as the result of nine years' experience in the manufacture and use of nitro-glycerine, guncotton, and dynamite, that the only condition of explosion of glycerine or dynamite is an elevation to a temperature of 360° Fahr., and that concussion or percussion will not produce such explosion, unless the conditions of the concussion are such, that the arrested motion raises a confined portion of substance to the exploding temperature. The explosion of this portion, however small, produces violent compression and consequent heating to 360° of the adjoining portion, and so on throughout, and thus the whole explodes.

He maintains that no amount of mere pressure will produce explosion, if such pressure is so slowly applied that the heat thereby generated is dissipated before it reaches 360°. Also, that the reason why nitro-glycerine, guncotton, dynamite, &c., burn inexplosively when a light is applied to their open unconfined surfaces, is that the heat under those circumstances is not communicated through the mass, as it is when violent percussive condensation is communicated throughout. He states that "a glowing coal, a hot iron, or a gas jet, applied to the bottom, or even the side of a tin, will explode it, for it will heat the film in immediate contact with it to the explosive point, producing initial explosion;" that "a bottle or other frangible vessel partially filled with nitro-glycerine may be thrown with great violence, or from a height, on a rock, and shattered, without producing explosion," while a tin vessel or

other strong flexible vessel, filled with nitro-glycerine and subjected to a similar ordeal, will invariably explode when it strikes." He accounts for this difference by the fact that the glass bottle breaks by first contact, releasing the contents and allowing them to scatter, and thus continuing the motion, while the flexible vessel is violently indented at the point of contact, and the motion is suddenly and violently arrested at this point, and such motion thus stopped is converted into heat. The exploding temperature thus attained, however momentarily and by however small a film, would produce the initial explosion, and thus would explode the whole.

Keeping in mind that guncotton, nitro-glycerine, dynamite, &c., are bad conductors of heat, Mr. Kalmbach's views become intelligible, and explain the apparent anomaly of the gradual combustion of these substances, when heated on their free surfaces. A lump of dynamite, a wad of *compressed* guncotton, or a mass of liquid nitro-glycerine, if thrown upon an open fire, would be heated *on its surface only* to the explosive point; the heat would not be conducted through it more rapidly than it would burn away superficially, and thus its combustion would resemble that of a squib, or of the solid non-granular gunpowder which the schoolboy prepares, by making common powder into a paste and drying it to a solid lump. This "fizzes," but does not explode, simply because it is an ill-conducting mass, heated only on its surface; whereas the granular gunpowder does explode, because the flame of the initial flash is projected throughout the interstices or

spaces surrounding each grain, and thus heats the whole mass and fires every grain at once, this sudden development of heated gas constituting the explosion. In like manner a wave of sudden condensation would be freely transmitted through nitro-glycerine, having the ordinary property of fluid elasticity; but a discrete solid made up of separate fibres, as guncotton, or separate non-cohering particles of silica-like dynamite, would, like a cracked tumbler or other discrete solid, refuse to transmit a wave of condensation, and at the same time be sufficiently plastic to yield smoothly at the point of impact. If I am right in thus attributing the superior safety of dynamite to its comparative inelasticity, rather than, as usually supposed, to its elasticity, an important principle is suggested for the guidance of the manufacturers of dynamites or other solid absorbents of nitro-glycerine. They should, in order to secure safety of transport and storage, select a solid absorbent having the smallest obtainable degree of vibratory elasticity, but which, at the same time, is capable of yielding to sudden pressure with the least possible amount of internal friction. In Nobel's dynamite this friction is reduced to a minimum, by the lubricant action of the absorbed oil which surrounds every silicious particle.

The fact that serious explosions have occurred, when frozen nitro-glycerine has been subjected to a degree of rough handling which the liquid might safely bear, may be explained by the fact that the frozen mass is made up of a number of crystals, the surfaces and angles of which must rub violently against each other

when the whole mass is jarred or much shaken; and if this friction should even instantaneously raise the smallest conceivable internal particle to the exploding temperature, an initial explosion that would fire the whole must be the result.

This kind of friction could not occur between the particles of a liquid. The mere fracture of a dry crystal will often cause explosion.

It is very important to all who handle nitro-glycerine that this dangerous speciality of the crystalline substance should be understood. The name of "frozen," which is commonly applied to this crystalline form of nitro-glycerine, naturally suggests a diminished liability to explosion, and this idea is apparently confirmed by the uncertainty of its explosiveness when intentionally fired in the ordinary way by a detonating fuse, and hence it has been handled less carefully than the liquid. The explosion of thirty cases at Newcastle in 1866, which killed the mayor of the town and three men engaged in burying them, apparently arose from this mistake; and I suspect that other unexplained accidents have originated in a similar manner, with wholly or partially crystallized samples.

The *fulminates* are a series of explosive substances, differing essentially in their chemical composition from any of those already described. They were formerly known under the names of fulminating silver, fulminating mercury, &c. Their modern name describes their theoretical composition as compounds of a metal with fulminic acid, itself a hypothetical substance, supposed to be composed of two equivalents of carbon,

two of nitrogen, and two of oxygen. This, combined with two equivalents of the metal (M), gives the following formula for a fulminate $C^2 N^2 M^2 O^2$, which corresponds with the actual analyses of fulminate of silver composed of:

Carbon	7·92
Nitrogen	9·24
Silver	72·19
Oxygen	10·65
	100·00

Cyanate of silver, CNAgO, yields the same results to analyses, but its properties are quite different; hence it is inferred, that although the materials and proportions are the same in both substances, their mode of combination is different; that there are two equivalents of each element in the fulminate and one of each in the cyanate. Fulminic acid has never been isolated, and the exact nature of the decomposition which occurs when fulminates explode, is not clearly understood by anybody, and has therefore been the subject of many very learned disquisitions.

We know that the elements of these compounds are held together by very loose affinities, that they separate very suddenly when heated or struck, and explode very violently by the sudden formation of gases, probably cyanogen and other nitrogen compounds; such compounds being found on examining the products of explosion; but whether they are formed directly in the act of explosion or by some after recombination of the loosened elements, is not easily determined.

The fulminates are easily prepared. By simply dissolving 1 part by weight of silver in 20 of nitric acid, and adding to the solution about 50 parts of alcohol, crystals of the fulminate of silver are freely formed. If recently precipitated oxide of silver is digested for twelve or fifteen hours in concentrated solution of ammonia, a black powder is precipitated, and may be separated by pouring off the liquid ammonia, and cautiously drying in small portions. This is another form of this fulminate. If the decanted ammoniacal liquid is now gently heated, small crystals of excessively sensitive fulminate will be deposited, so sensitive that they will scarcely bear touching. Fulminate of silver is also readily formed when ammonia is added to the nitrate or other salt of silver, and explosions may easily occur from its accidental production, unless the conditions of its formation are understood. This precaution is especially necessary, as the ammonia-nitrate of silver is now rather extensively used by amateurs and others in silvering glass for telescope specula, common mirrors, and for ornamental purposes.

The fulminate of silver occurs either in the form of small brilliant crystalline needles or scales, or as the dark-coloured powder above mentioned, according to the mode of preparation. The crystalline form is the most sensitive. It is unsafe even when moist, and when quite dry will explode on the touch of a feather. Many serious accidents have occurred in experimenting with it, and few have escaped unscathed who have prepared it to any considerable extent. It is liable to what appears to be spontaneous explosion. If about

half a grain be placed upon the end of a penknife and exploded, the portion of steel upon which it rested will disappear. Not more than one or two grains should be exploded at once within any building. Its extreme sensitiveness renders it of little or no practical use.

Fulminate of Gold may be prepared, like fulminate of silver, by treating solutions of gold with ammonia. It is a brownish yellow or an olive-coloured powder, according to the mode of preparation, and, like the silver fulminate, too sensitive and powerful to be safely handled or stored at all.

Fulminate of Platinum, with similar properties, may be prepared in like manner.

Fulminates of antimony, bismuth, copper, lime, &c., are obtainable, and are less sensitive than those of gold, platinum, and silver, but have not been practically used.

The most important of the fulminates is that of mercury, which may be prepared by dissolving 1 part of mercury in 12 of nitric acid of specific gravity 1·36, and adding to the solution 11 parts of alcohol of specific gravity 0·850, then gently heating the mixture by means of a water bath. Violent reaction and effervescence follow, nitric ether is liberated, metallic mercury is deposited, and the fulminate is formed as yellowish-white grains. These, when cold, should be washed with cold water to separate free acid, &c. The fulminate thus obtained is soluble in boiling water, and on cooling the solution, it is deposited in a state of purity as fine silky crystalline needles.

It detonates violently on percussion or strong friction, but is not so sensitive as the fulminate of silver. It explodes when heated to a temperature between 300° and 400° Fahr. In either case its explosion is accompanied with a flame of considerable intensity, which is projected outward with great force. When moistened with 20 to 25 per cent. of water, it may be stored and carried with safety if proper precautions are used. It should never be transported by railway. Guttapercha vessels are commonly used for its storage.

It is largely manufactured and used for the priming of percussion caps and detonating fuses, for which purposes it is more or less diluted with gunpowder, with a mixture of nitre and sulphide of antimony, or other less powerful explosive. The proportions and the substances used for this purpose vary considerably. Ten parts fulminate and 6 parts gunpowder, made into a dough with mortar, and mixed with the moist fulminate, is one of the compositions used in France; $2\frac{1}{2}$ lb. of this is used for charging about 40,000 caps. Two parts fulminate, one of nitre, and one-and-a-half of sulphide of antimony or sulphur freely powdered, is another formula.

At Woolwich Arsenal, a little more than a grain of the mixture of fulminate, nitre, and sulphide of antimony is dropped into each cap by means of a perforated plate placed over a number of caps. The charge of each cap is then slightly pressed and secured in its place by means of a drop of varnish. A wad of tinfoil is sometimes added.

Serious accidents continually occur in the mixing of

fulminate and priming of caps. The only practical means of averting, or rather moderating these, is the strict limitation of quantities to be used at one time.

The Gunpowder Act of 1860 provides that—

No such manufacture shall be carried on without a licence.

It shall not be manufactured within 100 yards of a dwelling house or occupied building.

Not more than 1 oz. of the dry powder, or 8 oz. mixed with 25 per cent. of water, shall be kept in any unlicensed place.

The operation of mixing the composition for percussion caps shall be performed in a building not less than 20 yards from any other workshop, and not more than 5 lb. of such mixture shall be in a mixing shop at any time.

No fulminating mercury, except that actually used in mixing, shall be kept in any building used in preparing the cap-composition, unless it be mixed with at least 20 per cent. of water.

No greater quantity than 24 oz. of cap-composition shall be at any one time in one building, where the operation of priming or loading is being performed.

This loading of caps shall not be performed in any building nearer than 50 yards to an inhabited dwelling or occupied house.

One of the most fearful implements of destruction in which the fulminate of mercury has been used, was the "Orsini bomb," used in Paris with such murderous effect on the 14th January, 1858. These bombs were ovoid iron shells, about 4 or 5 inches long and 3 or

4 inches wide, studded around with ordinary gun-nipples communicating with the interior containing the charge of fulminate.

As I was unwittingly concerned in this tragedy—as the chief actors are now dead, and the wrongs which stirred the passions that led to its perpetration have since been fully and happily redressed—I may now reveal a few facts that have not hitherto been made public.

I was first introduced to Felice Orsini, a highly-educated, refined, and courteous Italian gentleman, in the autumn of 1857, and having lived for awhile in Italy, and witnessed the iniquities of the Austrian, Papal, and Ducal despotisms that crushed the nation, I heartily sympathized with his patriotic yearnings for the liberation of his country. He told me that the people were preparing for a great effort to repel the Austrians, and drive the French army of occupation from Rome, but that the search for arms was so rigorous that no ordinary weapons could be imported or held by the Italian patriots. He had therefore invented a new form of stellar gas-burner, which could easily be converted into a bomb by simply unscrewing the radiating gas-nipples and replacing them by gun-nipples, or by making the gas-nipples small enough to fit percussion caps. This gas-head, or receptacle, was to be filled with an explosive composition, plugged at the place where it screwed to the gas-pipe, and the nipples armed with caps. It might then be used as a hand-grenade to be thrown from house tops and windows among any soldiers of the enemy, who should

attempt to occupy the streets and fire upon the population of an insurgent town.

But these gas-burner shells were too small for a charge of ordinary gunpowder to produce effective explosion. I suggested the fulminate of mercury in lieu of powder, made some, and taught Orsini and Pieri how to make it themselves. They also learned how to make fulminate of silver, and some other detonating compounds, and proposed to use the dark-powder form of silver fulminate as priming for the caps, fearing that the blow produced by the fall of the small bomb would not be sufficient to ignite ordinary caps. I pointed out the danger of placing such caps on the nipples; but Orsini replied that the sacrifice of a few individual lives was a trifling evil compared with the living death that all Italy was then enduring.

They never showed me any of the bombs, only described them, and their description indicated a much smaller size than those actually used in Paris; I understood that they would be but little larger than a hen's egg, and suspect that such was the original idea. I still believe that *at first* Orsini really intended them for the purposes he named to me, and that the idea of removing the French army of occupation from Rome, by killing the Emperor and causing a revolution in Paris, was an after-thought of his own, or a suggestion of Pieri, a crafty, sinister man, likely to choose a crooked course of action.

It was stated at the trial that ordinary caps were used; but I have little doubt that they were charged either with silver fulminate or with pure fulminate of

mercury. The readiness with which those thrown from so short a distance exploded, and the great care with which Orsini deposited his unthrown shell in the gutter and wetted it over with the blood from his wound, indicate this.

When Orsini and Pieri called upon me on leaving England for the last time, Pieri said they were bound for Ferrara (on the confines of the Austrian territory), where the rising was to commence. Orsini said nothing concerning their destination, but informed me that he had prepared a quantity of the fulminate of mercury, and packed it moist in pots as "dentifrice," or tooth-paste, and perfumed and labelled it accordingly.

Orsini in his final confession stated, that the English chemist who taught him how to make the fulminate had no knowledge of its intended purpose. This assurance was accepted by the Emperor and the French police, who gave me no further trouble than that of a few days' secret watching of my movements in Birmingham, which was so delicately conducted that I only discovered it accidentally.

The *chloride of nitrogen* already mentioned is very easily prepared, by simply inverting a bottle of chlorine gas over a solution of one part chloride of ammonium in twelve of water. A yellowish oily liquid is gradually formed, which falls to the bottom of the tray or dish (which should be of lead) containing the solution. This is one of the most dangerous compounds known. It explodes with fearful violence if heated only to 200°, when brought into contact with any kind of fixed or

volatile oil, phosphorus, and many other inflammable substances, or when subjected to the slightest shock or friction. It will not even bear the touch of a feather, and has been known to explode by falling upon the surface of water. It is utterly useless, and my advice to all is, "Don't prepare it, nor meddle with it at all." Its explosion appears to be due to the feebleness of the affinities holding the two gaseous elements together, and their consequent facility of dissociation and expansion.

Iodide of nitrogen is analogous to this, but less dangerous. It is readily prepared by merely placing a little solid iodine in a cold and strong solution of ammonia. The iodine loses its crystalline structure, and a powder of nearly the same colour as the original iodine remains. The ammonia may be decanted from this, or more safely filtered away on blotting paper. While quite wet it may be handled, but immediately it becomes dry, or nearly so, it explodes with great violence, giving off violet fumes of iodine when merely touched. Those who prepare it from curiosity should only make two or three grains at once; these will be quite sufficient to display its properties, especially if they should get a little under the finger nail, as I once did. On one occasion I had several small specimens prepared for lecture illustration, and lying on filter papers on the lecture table. The vibration caused by a sudden closing of the theatre door exploded them all.

In conclusion, I must offer a few words of caution and advice to all who meddle with any of these ex-

plosives, either for commercial or philosophical purposes, or for mere amusement.

At first you will be very cautious, will follow all the instructions and warnings you may have received in order to prevent accident. You will probably escape thereby, may possibly do so even though you be as impetuous and impatient as Orsini, who tested his first-made sample of fulminate by stamping upon it with his foot, and escaped with no further damage than shattering the heel of his boot. This impunity may be repeated a few times with progressive diminution of precautions, until at last you will probably begin to suppose, that after all these things are not so dangerous as represented. It is just at this stage that they become really and practically dangerous; the more completely you have escaped hitherto, the greater your present and future risk. The adage that "familiarity breeds contempt" is never more fully verified than in handling explosives. So convinced am I of this tendency (and this conviction is based upon my own experience and the observation of that of many others), that I regard every building in which explosives are manufactured or stored as doomed to destruction, and the longer it has been in the same hands and has escaped its inevitable doom, the more likely is it to be blown up to-day or to-morrow. My friends smiled at my habit of always crossing the road when passing Walker's old percussion-cap manufactory in Birmingham, and told me how long the manufacture had been there conducted without accident. "The sooner must it go," was my reply, "if the proprietors or *any* of their work-

men share your confidence in its safety." It did go at about this time, and many lives were destroyed. The proprietor, his workpeople, and several neighbours, whose houses were shattered, were the victims, and among them was one who was merely passing through the street. Subsequent inquiry showed that the proprietor had become so indifferent to the dangerous properties of the fulminate, that he commonly carried a packet containing several pounds of dry priming from the manufactory to the priming-house, and rode in a public omnibus through the streets of Birmingham with this on his lap. A collision with another vehicle, or a break-down of any kind, would probably have exploded his "luncheon," and have left but small fragments of himself, the omnibus, and its contents, besides knocking down the houses on each side of the street, and killing or maiming the surrounding passengers. But Mr. Walker was not a naturally reckless man, nor indifferent to the safety of his neighbours. It was the long-continued impunity which had led to the over-confidence to which the final destruction of the cap-works was probably due, and which ultimately brings all such establishments to an end, and has destroyed the lives of so many connected with them.

The growth of this confidence is perfectly natural, and is so gradual that it escapes the ordinary vigilance of its prospective victim; this natural moral weakness magnifies all the physical dangers of explosives, and therefore all who handle such things should be specially self-searching to guard themselves against its fatal tendency.

"THE EXPLOSIVES ACT OF 1875."

As this Act was in course of legislation during the time the above was written, and will come into operation at about the same time as the publication of this volume in 1876, I make the following abstract of its leading essentials as an appendix.

It applies to gunpowder, nitro-glycerine, dynamite, guncotton, blasting powders, fulminates, and all other substances used or manufactured on a practical scale to produce explosion or pyrotechnic effect.

Law Relating to Gunpowder.

It shall not be manufactured either wholly or partially, excepting at a licensed gunpowder factory; small quantities made for purpose of chemical experiment and not for sale or practical use being excepted.

The penalty for infringement, shall be forfeiture of all materials and fine not exceeding 100*l.* per day for evey day during the manufacture.

It shall not be kept in any place excepting a licensed factory, magazine, or store. This does not apply to powder kept for private use in quantities not exceeding 30 lb. on the same premises, nor to carriers conveying it in accordance with the regulations of the Act.

Penalty for infringement, forfeiture of powder and fine not exceeding two shillings per pound.

The application for licence for factories or magazines

to be made according to specified form, and assent of local authority to be obtained.

Gunpowder factories and magazines to be used for no other purpose. No iron or steel or gritty substances to be exposed in any part of such buildings. All buildings to be provided with efficient lightning conductors, unless the Secretary of State considers (from position, &c.) that it is unnecessary. Charcoal, oiled cotton, oiled rags, oiled waste, and other articles liable to spontaneous combustion not to be left in any danger building, excepting while in use. Gunpowder to be removed from any room or building during any repairs. Copy of these rules and statement of permitted quantity of powder or ingredients, in a form easily to be read, to be constantly kept affixed to every danger building.

All tools and implements used in danger building to be made of wood, copper, brass, or some soft metal or material, or covered with such. The introduction of lucifer matches, grit, &c., to be prevented by use of suitable clothes without pockets, suitable shoes, searching, &c. Smoking prohibited. No person under 16 years of age to be admitted or employed, except in the presence or under the supervision of a grown person. All finished powder to be removed at once from factory to magazine. All ingredients to be sifted before mixing to remove dangerous impediments. Carriages, boats, &c., for conveying wholly or partially finished powder, to be constructed and treated similarly to factories and magazines.

Proprietors allowed to make and enforce by penalties

not exceeding 40*s*., special rules, subject to the sanction of the Secretary of State.

Existing manufactories must obtain continuing certificate under this Act, subject to the following regulations:

Not more than 50 lb. of ingredients to be ground under one pair of stones in incorporating mill, and all such mills to be provided with house for store of mill charges, situated at safe distance, and properly constructed of stone or brick.

Not more than 10 cwt. to be subjected to pressure at one time.

Not more than 12 cwt. to be corned and granulated at one time and place.

Not more than 50 cwt. to be dried at one time in one stove or place. The quantities allowed in any press, corning, or granulating house not to exceed the quantities to be operated upon as above stated.

Every gunpowder mill to be provided with good and sufficient factory, magazine, or magazines at least 140 yards distant from mill, unless otherwise authorized by special certificate.

No charcoal to be kept within 20 yards of any part of powder mill.

The general regulations for *consumers' stores* are similar to the above for mill stores. A licence for such store must be obtained from local authority, this license describing site, &c., and the quantity permitted to be stored. Licences are not transferable to other persons, and must be annually renewed. Her Majesty may from time to time, by order of Council, regulate the

construction, materials, fittings, buildings, &c., of such stores, their distances from other buildings, and the maximum amount to be stored in each—not exceeding 2 tons—according to their construction and distances from other buildings.

The present regulations are—That the store shall be exclusively for the use of a mine, quarry, or factory for safety fuses. The amount in store not to exceed 4000 lb. if the store is well built of brick and stone, and in other cases 300 lb. Stores exceeding 300 lb. to be within 200 yards of mine, quarry, &c., where the powder is to be used, and not within 200 yards of any inhabited house without occupier's written consent. The store shall not be within the City of London or Westminster, or within three miles of them, nor within 1 mile of any borough or market town, or within 2 miles of any royal residence or gunpowder magazine belonging to the Crown, nor within half a mile of any parish church.

Retail dealers in gunpowder are required to register their premises with local authority, and must keep the powder in a house, building, or fire-proof safe. If such place of storage is substantially constructed, specially devoted to the purpose, and at a safe distance from a public highway or place, the maximum amount allowed is 200 lb. If kept in a fire-proof safe within a dwelling house or other ordinary building, 100 lb. If so kept without fire-proof safe, 50 lb. Explosive and highly inflammable substances in all cases to be kept within safe distance from the powder, and the special building or safe to be constructed without any exposed

iron or steel in the interior, and all quantities exceeding 1 lb. to be kept in a substantial closed case, bag, canister, or other receptacle.

In all factories, magazines, or stores of any kind, all gunpowder or ingredients within a radius of 20 yards from the building shall be considered as in the building. All places adjoining each other and occupied together to be regarded as one place.

Gunpowder shall not be hawked, sold, or exposed for sale in any public place or thoroughfare. Shall not be sold to children under thirteen years of age. Penalty not exceeding 5*l.* Quantities exceeding 1 lb. only to be sold or exposed for sale in substantially constructed and closed cases, bags, or canisters.

Conveyance of Gunpowder.

Whether under or above 5 lb. to be contained in substantial case from which the powder cannot escape; such cases to be subject to approval of the Government inspector, and not used for any other purpose. No uncovered iron or steel to be used in construction of cases, and their interiors to be kept free from grit. 100 lb. the maximum allowed in one package, except under special conditions approved by inspector. The word "gunpowder" in conspicuous characters to be affixed to outside of each package.

All harbour authorities, railway companies, canal companies, wharfingers, &c., shall make bye-laws for regulation of conveyance, loading, and unloading of gunpowder, subject to the sanction of Board of Trade. The various matters to which these bye-laws shall

refer are specified in detail in the Act. The Secretary of State or Board of Trade shall receive and consider any objection to these bye-laws which may be made by any corporation or private persons who may be affected by their operation.

Other Explosives.

Safety cartridges made with gunpowder may be stored and carried in five times the quantity of gunpowder. The outermost package of all explosives, other than gunpowder, to be labelled conspicuously with the name of the substance and the word "explosive." Her Majesty by order in Council may prohibit the manufacture, storage, and carriage of specially dangerous explosives.

In a subsequent order of Council, dated August 5, 1875, and published under the title of "Order in Council—Classifying Explosives," the following classification is adopted:

Class 1.—Gunpowder.
" 2.—Nitrate Mixture.
" 3.—Nitro Compound.
" 4.—Chlorate Mixture.
" 5.—Fulminate.
" 6.—Ammunition.
" 7.—Firework.

These are fully defined in the body of the Order.

A second Order or "Notice" on "Packing of Explosives other than Gunpowder."

A third notice on the "Conveyance, &c., of Explosives" states the regulations for each of the above-named classes.

Fourth notice, on "Stores Licensed for Mixed Explosives."

Fifth notice, "Gunpowder Stores," contains detail of supplementary regulations on this subject.

Sixth notice, refers to "Small Firework Factories."

The details of these notices would occupy too much space here. Those interested in them may obtain copies of either at one penny each from most booksellers.

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